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Ce document présente la synthèse d'un rapport d'étude sur l'enseignement des sciences et des mathématiques au primaire et au secondaire en Amérique du Nord. La première partie trace les grandes lignes des principales études internationales, canadiennes, américaines et provinciales faisant le point sur l'enseignement de ces disciplines. La deuxième partie décrit certaines mesures qui ont été prises en vue de renouveler les orientations et les pratiques touchant ces domaines. Il ressort entre autres que les élèves nord-américains paraissent moins bien réussir en mathématiques et en sciences que leurs homologues d'Europe et d'Asie. Cependant, les jeunes Canadiens obtiennent des résultats un peu supérieurs à ceux de leurs voisins américains. Par ailleurs, les Etats-Unis ont beaucoup investi pour rendre l'enseignement des sciences et des mathématiques compétitif au plan international et pour suivre les nouvelles tendances. Au Canada, il n'y a pas eu d'investissement comparable au plan national; les actions ont surtout été entreprises par les provinces ou à un niveau local. Le rapport d'étude complet est présenté en annexe.

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Conseil de la science et de la technologie

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L'enseignement des sciences et des mathématiques en Amérique du Nord:

EN PROGRÈS OU EN DÉCLIN?

Par: Graham Orpwood

Québec

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en Amérique du Nord :

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Conseil de la science et de la technologie

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Avant-propos

Soucieux de la préparation de la relève scientifique et technique pour la génération de chercheurs actuellement en poste, le Conseil de la science et de la technologie du Québec s'interroge sur les conditions prévalant dans l'enseignement des sciences et des mathématiques dans les écoles primaires et secondaires.

Aussi, afin de mieux évaluer les efforts réalisés au Québec en vue d'améliorer cet enseignement, le Conseil a demandé à M. Graham Orpwood, d'Orpwood Associates, de réaliser une étude permettant de situer les réflexions et les réalisations québécoises dans le contexte nord-américain. C'est avec plaisir que nous rendons publique la traduction française de la synthèse de cette étude.

Cette traduction précède la version anglaise de la synthèse (voir «Discussion paper») et, en annexe, le Conseil présente la version anglaise du rapport d'étude ayant servi à la préparation de cette discussion.

Bien entendu, les opinions et les conclusions de l'auteur de cette publication ne reflètent pas nécessairement celles du Conseil.

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L'enseignement des sciences et des mathématiques
en Amérique du Nord:

EN PROGRÈS OU EN DÉCLIN ?

- SYNTHÈSE -

par

Graham Orpwood

Conseil de la science et de la technologie

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Préface

Le présent document de travail a été préparé à la demande du Conseil de la science et de la technologie afin de passer en revue les études et les mesures récentes ayant trait à l'enseignement des sciences et des mathématiques en Amérique du Nord.

De nos jours, en Amérique du Nord, l'enseignement des sciences et des mathématiques au primaire et au secondaire est l'objet de préoccupations, d'évaluations et de réformes importantes. Afin de situer la discussion de l'aspect québécois de ces questions dans un contexte nord-américain, l'étude vise deux objectifs principaux :

1. Le premier est de passer en revue les études les plus importantes concernant l'enseignement des sciences et des mathématiques au primaire et au secondaire effectuées ces dernières années et d'en relever les principales constatations ;

2. Le second est de décrire certaines mesures significatives prises en Amérique du Nord dans le but d'améliorer l'enseignement des sciences et des mathématiques au primaire et au secondaire.

La première phase de l'étude a fait l'objet d'un rapport détaillé comprenant des résumés d'un grand nombre d'études et de recherches publiées depuis cinq ans. Le rapport se subdivise en deux parties correspondant aux deux objectifs susmentionnés : l'étude de l'enseignement des sciences et des mathématiques et les mesures destinées à améliorer cet enseignement. La partie A traite de quatre types d'études : les études internationales, les études canadiennes et américaines réalisées à l'échelle nationale, ainsi que les études effectuées dans les provinces canadiennes. La partie B traite des mesures prises dans l'ensemble des États-Unis et du Canada, ainsi que de celles adoptées par les états et les provinces.

Le présent document diffère du rapport principal tant par sa forme que par son but. Alors que le rapport complet comportait un compte rendu systématique des principales études sur l'enseignement des sciences et des mathématiques en Amérique du Nord, le document-synthèse présente une analyse de chacun de ces rapports ; il cherche à provoquer une discussion sur les aspects de l'enseignement des sciences et des mathématiques qui ont le plus attiré l'attention des organismes et des chercheurs, ainsi que sur les orientations et les pratiques visées par les changements préconisés.

Le lecteur peut trouver préférable de lire à la fois l'étude complète et détaillée[1] et la synthèse. Les deux documents sont toutefois complets en soi et peuvent être lus de manière indépendante.

1 Orpwood Associates a préparé, pour le Conseil de la science et de la technologie, un rapport intitulé *Science and Mathematics Education in North America: Advance or Decline ?*. Monsieur Orpwood a ensuite préparé un «Discussion paper». Les deux textes sont présentés, ci-après, en version originale anglaise. La synthèse que voici constitue une traduction du «Discussion paper».

Introduction

De nos jours, peut-être plus que jamais auparavant, la science, la technologie et les mathématiques sont cruciales dans presque toutes les activités humaines. La plupart des questions brûlantes de notre époque ont un côté scientifique, qu'il s'agisse de l'environnement, de la portée des missiles ou de la viabilité du fœtus. De plus, les progrès technologiques réalisés dans le domaine des communications ont provoqué des changements fondamentaux dans plusieurs domaines. Par exemple, les contacts humains directs à la bourse, tant au plan local que national, prennent de moins en moins d'importance dans un monde où l'ordinateur rend possible le commerce global au simple toucher d'un clavier. Par ailleurs, les transmissions par satellite nous permettent de voir à la télévision des manifestations, des émeutes et même des combats au moment même où ils surviennent. Cela signifie que nous ne sommes plus obligés de nous fier aux nouvelles « officielles » des autres nations pour savoir ce qui s'y passe. Ce fait peut aussi influer sur les événements eux-mêmes.

L'impact considérable de l'ordinateur et des autres technologies sur le marché du travail accroît sans cesse l'impact de la science et de la technologie sur l'industrie et le commerce, qui sont actuellement au cœur d'un bouleversement comparable à la révolution industrielle. Partout dans l'industrie, l'exploitation des matières brutes cède la place de façon relativement importante à l'utilisation de l'informatique et à la mise au point d'autres applications nouvelles des connaissances et des aptitudes scientifiques.

Il en résulte, depuis quelques années, un renouveau d'intérêt et de préoccupation à l'égard de l'enseignement des sciences et des mathématiques au fur et à mesure que la société prend conscience des changements fondamentaux qui se produisent dans l'ensemble de l'économie en ces dernières décennies du XX^{e} siècle. Ces changements sont si importants, qu'à l'avenir, tous les citoyens informés devront posséder un minimum de connaissances scientifiques et technologiques, même s'ils n'en ont pas la compréhension profonde que doivent posséder les spécialistes.

De toute évidence, un facteur vital pour toutes les économies nationales sera la manière dont les citoyens d'un pays pourront faire face au défi d'intégrer ces changements. En d'autres termes, ne serait-ce que pour se maintenir au même niveau que le reste du monde, les citoyens d'un pays devront maîtriser les habiletés et les connaissances de base, et faire preuve d'un génie inventif crucial.

Le sentiment populaire que nombre d'éditoriaux et d'articles expriment est que les Nord-Américains sont loin derrière le reste du monde en matière de formation scientifique et technologique des jeunes. De plus, on croit que cette situation se détériore progressivement. De nombreuses études sur l'enseignement des sciences et des mathématiques ont été entreprises au cours des cinq ou dix dernières années afin d'évaluer la situation réelle de la population étudiante et des écoles dans ce contexte ; de surcroît, bon nombre de plans, de stratégies et de mesures ont été mis à l'essai. C'est pourquoi le présent document se divise en deux parties : une première qui trace les grandes lignes des nombreuses études faisant le point sur l'enseignement des sciences et des mathématiques et une deuxième qui décrit quelques-unes des multiples mesures qui ont été prises afin de renouveler les orientations et les pratiques touchant ces domaines.

A Les études sur l'enseignement des sciences et des mathématiques

Les études sur lesquelles reposent la présente synthèse et le rapport complet sont toutes mentionnées dans la bibliographie. Afin de rendre la discussion aussi accessible que possible, nous n'utilisons pas de notes en bas de page. À la place, des chiffres entre parenthèses renvoient le lecteur au document approprié dans la bibliographie.

L'Association internationale pour l'évaluation du rendement scolaire a commandé deux études : l'une, internationale, sur les mathématiques, *The Underachieving Curriculum : Assessing U.S. Mathematics from an International Perspective* (1) et l'autre, également internationale, *Science Achievement in Seventeen Countries : A Preliminary Report* (2), sur les sciences. Parmi les autres études internationales, il faut compter la première évaluation internationale des progrès en enseignement, publiée sous le titre *A World of Differences: An International Assessment of Mathematics and Science* (3) et un document de recherche, *Mathematics Achievement of Chinese, Japanese and American Children* (4), sur le rendement des enfants chinois, japonais et américains en mathématiques.

Les études nationales canadiennes et américaines passées en revue sont les suivantes : le rapport de 1984 du Conseil des sciences du Canada, *À l'école des sciences : la jeunesse canadienne face à son avenir* (5), la partie canadienne de la deuxième étude internationale sur les sciences, *Science Achievement in Seventeen Countries : A Preliminary Report* (2), l'étude de 1986 de la (US) National Assessment of Educational Progress (NAEP) sur les mathématiques, la première étude de la National Assessment of Computer Competence (NAEP), *The Mathematics Report Card : Are We Measuring Up ?* (6), une évaluation de la compétence en informatique réalisée en 1986, *Computer Competence : The First National Assessment* (7), l'étude de 1986 de la NAEP sur les sciences, *The Science Report Card: Elements of Risk and Recovery* (8) l'étude de la (US) Research Triangle Institute's *Report of the 1985-1986 National Survey of Science and Mathematics Education* (9), une enquête nationale sur l'enseignement des sciences et des mathématiques, l'enquête de l'American Institute of Physics réalisée en 1986-1987 sur les enseignants de physique du secondaire, *Physics in the High Schools* (10) et, enfin, le rapport de 1988 de l'Office of Technology Assessment du Congrès américain intitulé *Educating Scientists and Engineers: Grade School to Grad School* (11).

Le rapport porte également sur six études provinciales : la *British Columbia 1986 Science Assessment* (12), l'*Alberta Diploma Examinations Program* and Triennial Assessment (13) ; un rapport spécial, *Science for Saskatchewan Schools* (14) ; le *Manitoba 1986 Science Assessment* (15) ; l'*Ontario Science Education Report Card* (16), une analyse des résultats obtenus en Ontario lors de la deuxième étude internationale sur les sciences et, enfin, l'étude correspondante basée sur les résultats du Québec, *L'enseignement des sciences dans les écoles secondaires du Québec* (17).

Les thèmes traités dans ces nombreuses études et les observations qui s'y trouvent formulées peuvent être regroupés sous trois rubriques : les étudiants, les enseignants et les programmes d'études. Pour les programmes, on peut encore faire la distinction entre les sciences et les mathématiques, même si les résultats qu'obtiennent ces deux sujets comportent de nombreuses similitudes.

• Le rendement scolaire

L'un des principaux points visés par presque toute la recherche qui nous intéresse est celui du succès scolaire. Dans l'ensemble, les élèves nord-américains paraissent moins bien réussir en mathématiques et en sciences que leurs homologues d'Europe et d'Asie. Cependant, les jeunes Canadiens obtiennent des résultats un peu supérieurs à ceux de leurs voisins américains.

Les mathématiques

Parmi les jeunes de 13 ans de 20 groupes et pays différents ayant fait l'objet d'une enquête internationale en mathématiques (1), les élèves japonais se classent premiers et les Canadiens se situent quelque part au milieu. La même étude montre qu'à 18 ans, les Canadiens réussissent moins bien que la moyenne dans un groupe de 15 pays. Il faut toutefois tenir compte du fait qu'une proportion élevée des élèves canadiens âgés de 18 ans suit des cours de mathématiques. Ce facteur affecte négativement la moyenne canadienne puisque les comparaisons internationales concernent des élèves qui ont le choix de suivre ou non un cours donné.

Une autre étude internationale (3) qui compare des jeunes de 13 ans d'Irlande, de Corée, d'Espagne, du Royaume-Uni, des États-Unis et de quatre

provinces canadiennes révèle une tendance similaire. Ce sont les jeunes Coréens qui réussissent le mieux à résoudre des problèmes de difficultés moyenne et supérieure en mathématiques, tandis que les Canadiens, avec des variantes par province et par groupe linguistique, se situent légèrement au-dessus ou au-dessous de la moyenne.

Une autre étude (4) comparant des élèves de mathématiques chinois, japonais et américains a montré que les enfants asiatiques réussissent déjà mieux que les enfants américains à *la maternelle* et que dès lors, le fossé s'élargit.

Pour les personnes qui s'inquiètent de la performance des élèves nord-américains en mathématiques comparativement à ceux des autres pays, ces résultats sont révélateurs. Se fondant sur le niveau de réussite généralement faible des élèves nord-américains en mathématiques, une étude américaine (6) conclut que les diplômés japonais du secondaire réussissent aussi bien en mathématiques que les diplômés américains du collégial. Chaque année, les entreprises américaines sont obligées de dépenser de grosses sommes d'argent pour alphabétiser leurs travailleurs, leur donner une formation élémentaire et des cours de rattrapage. Les tendances démographiques indiquent que, dans un très proche avenir, un nombre croissant de personnes provenant des groupes de la population qui sont d'ordinaire les plus faibles en mathématiques entreront sur le marché du travail.

Au Canada, la situation n'est pas aussi mauvaise qu'aux États-Unis, mais le problème est préoccupant, tout de même. Les résultats obtenus au Canada ne permettent cependant pas de faire des comparaisons avec l'ensemble de la population. Il faut mentionner qu'en Alberta (13), une évaluation des élèves des 3^{e}, 6^{e} et 9^{e} années a révélé que près de 90 % des élèves évalués atteignent ou dépassent la norme provinciale et que 24 % ont été jugés exceptionnels ou mieux encore.

Les sciences

En enseignement des sciences, les tendances sont très semblables à celles des mathématiques. Les élèves nord-américains se situent à un niveau égal ou inférieur à la moyenne des différentes nationalités visées, tandis que les élèves du Japon, de Corée, de Hong-Kong et de Singapour obtiennent régulièrement les meilleurs résultats. Les Canadiens sont toutefois bien meilleurs que les Américains. Une étude internationale (3) révèle qu'à l'âge de 10 ans, les enfants

canadiens se classent au sixième rang en sciences par rapport à ceux de 15 pays. Ils sont au quatrième rang sur dix-sept à 14 ans, mais glissent au onzième ou au douzième rang sur treize à 17 et à 18 ans.

Comme en mathématiques, ces résultats ne sont pas aussi sombres qu'ils ne le paraissent a priori. En effet, il faut aussi tenir compte du fait qu'un grand nombre d'élèves canadiens poursuivent leurs études jusqu'à 17 et 18 ans, alors que les écoles secondaires des pays dont les élèves obtiennent les meilleurs résultats ont uniquement pour but de former une élite. En d'autres mots, l'échantillon canadien regroupe des jeunes dont les aptitudes scolaires varient beaucoup plus que celles des élèves asiatiques. Les écoles canadiennes parviennent donc mieux que celles des autres pays à assurer une formation scientifique élémentaire à un nombre de jeunes relativement important, mais elles réussissent moins bien à assurer une formation supérieure à une élite. Cette situation soulève d'importantes questions d'orientation pour ceux qui se préoccupent d'excellence et d'égalité des chances.

Une autre comparaison (3) concernant cette fois des jeunes de 13 ans de plusieurs provinces canadiennes, d'Irlande, d'Espagne, de Corée, du Royaume-Uni et des États-Unis révèle que la plupart des Canadiens qui étudient les sciences se situent à un niveau égal ou légèrement inférieur à la moyenne internationale. L'enquête révèle que les meilleurs élèves sont, bien sûr, les Coréens, mais aussi qu'ils sont suivis de près par les élèves de la Colombie-Britannique.

Aux États-Unis, les auteurs d'une étude sur la réussite des jeunes en sciences (8) estiment que les connaissances des jeunes Américains sont (dans les termes mêmes du rapport) « désespérément faibles ». L'examen des résultats de 1969 à aujourd'hui révèle que la compétence des jeunes Américains en sciences a diminué entre 1969 et 1982. Depuis 1982, la courbe remonte, mais plus de 50 % des Américains de 17 ans n'ont pas les connaissances qu'il leur faudrait pour pouvoir entreprendre un emploi où la science intervient, et seulement 7 % des individus du même groupe d'âge sont préparés adéquatement pour poursuivre des études en sciences au collège. Aux États-Unis toujours, les sous-groupes — soit les Noirs et les Hispaniques — accusent un retard en sciences d'au moins quatre ans par rapport à la moyenne.

Les résultats canadiens en sciences (12, 15, 16 et 17) se comparent à ceux obtenus en mathématiques : ils ne s'avèrent pas aussi mauvais que ceux des élèves américains, mais ils ne sont pas particulièrement bons non plus. Par exemple, les élèves de 3^{e} année au Manitoba sont incapables d'effectuer des mesures et de manipuler des données scientifiques et ceux de 6^{e} année ont une piètre maîtrise des procédés scientifiques et démontrent peu d'aptitudes de

niveau supérieur. Les deux groupes ont de la difficulté à répondre aux tests écrits. Les élèves de 9e année sont particulièrement faibles dans l'observation, dans la formulation d'hypothèses et dans l'identification des relations de cause à effet.

Les résultats obtenus par les jeunes Ontariens se situent à peu près dans la moyenne nationale en sciences. Les élèves québécois de 6e année obtiennent des résultats au-dessus de la moyenne, ceux de 9e année se situent dans la moyenne et ceux de 11e année, au-dessous. La province canadienne dont les élèves affichent les meilleurs résultats en sciences est la Colombie-Britannique. En fait, la réussite des élèves de cette province s'améliore avec le temps.

En résumé, on peut affirmer que, tant en mathématiques qu'en sciences, les élèves canadiens se situent en général près de la moyenne et qu'ils ne sont ni les meilleurs, ni les pires. Il semble toutefois que les attentes de la société vis-à-vis de la formation en sciences augmentent plus rapidement encore, car la population croit à tort que le succès scolaire diminue.

• Les mathématiques et les sciences selon le sexe

Les études sur les élèves de mathématiques et de sciences analysent également deux autres variables. La première est la différence selon le sexe et la seconde, l'ensemble des attitudes. Les conclusions des études touchant ces deux points sont moins nombreuses que celles touchant le rendement général, mais elles révèlent néanmoins des tendances claires.

Les études américaines sur l'enseignement des mathématiques (3, 6 et 7) montrent moins de différences entre le degré de réussite des garçons et des filles qu'on pouvait s'y attendre. L'une des conclusions proposées est que si les filles tendent à avoir une meilleure connaissance de base des mathématiques que les garçons, ces derniers obtiennent de meilleurs résultats dans les applications de niveau supérieur. Les garçons se révèlent aussi un peu plus habiles que les filles en informatique, domaine où l'influence familiale semble constituer un signe avant-coureur extrêmement important de la réussite.

La tendance générale en ce qui concerne la différence entre les deux sexes dans l'enseignement des sciences est que les filles réussissent aussi bien que les garçons au début de leur carrière scolaire, mais qu'un fossé semble se creuser et s'élargir à partir de l'âge de 12 ou 13 ans (2, 3, 8 et 16). L'existence de ce fossé se manifeste dans la réussite, dans l'attitude et dans les attentes face à la carrière.

En ce qui concerne l'attitude et la réussite, une différence majeure apparaît en physique aux dernières années du secondaire : les filles ont tendance à peu aimer la physique et choisissent de l'éviter. Elles ont pourtant une attitude tout à fait positive envers la biologie. Certaines des explications avancées veulent que les enseignants attendent davantage des garçons en sciences et que les manuels font une nette discrimination entre les deux sexes et donnent presque exclusivement des hommes comme modèles de comportement dans les laboratoires scientifiques et en technologie.

- **Les attitudes envers les mathématiques et les sciences**

Certaines études permettent de comparer l'attitude des élèves envers les mathématiques et les sciences (3, 4 et 6). À la lumière des tendances observées concernant la réussite, les résultats obtenus ne sont pas surprenants. En mathématiques, les élèves asiatiques prennent manifestement la question au sérieux et reçoivent l'encouragement de leur famille. Par exemple, 90 % des élèves japonais et chinois ont leur propre bureau à la maison et de 30 à 50 % des familles achètent des manuels complémentaires au programme scolaire. Aux États-Unis, 63 % des élèves disposent d'un bureau à la maison, mais seulement 1 % des familles achètent des manuels de mathématiques.

Les élèves asiatiques ont une attitude positive envers les devoirs, tandis que les jeunes d'Amérique du Nord ont une attitude généralement négative envers les devoirs et en font moins. C'est aussi le cas du Québec (17).

Aux États-Unis, l'attitude des élèves envers les mathématiques se détériore au fur et à mesure qu'ils progressent à l'école ; aux niveaux supérieurs, les mathématiques ne sont pas considérées comme pertinentes au monde du travail, et une faible proportion des élèves américains du secondaire opte pour des cours de mathématiques avancées.

La constatation majeure concernant l'attitude des élèves envers les mathématiques est que seulement 23 % des jeunes Coréens de 13 ans — qui comptent pourtant parmi ceux qui réussissent le mieux au monde en mathématiques — se jugent bons. De plus, la plupart des mères asiatiques ne sont pas satisfaites du degré de réussite de leurs enfants en mathématiques. À l'opposé, la plupart des jeunes Américains du même âge (66 %) — qui se classent parmi ceux qui réussissent le moins bien au monde en mathématiques — se jugent bons, et

leurs mères se disent satisfaites de leur rendement. Une suffisance aussi mal fondée étonne ...

Par ailleurs, les constatations concernant les attitudes vis-à-vis l'enseignement des sciences s'avèrent moins surprenantes. Une étude internationale (2) indique que la plupart des enfants ont au départ une attitude assez positive envers les sciences. Une étude canadienne (16) montre que cette attitude se modifie à partir de la 9e année environ et que, au deuxième cycle du secondaire, la physique devient le cours le moins populaire et la biologie, l'un des plus populaires.

Plusieurs études soulignent que les enfants ont une attitude assez positive envers les sciences proprement dites et envers l'école, mais qu'ils développent une attitude négative envers les cours de sciences donnés à l'école. Plus d'élèves canadiens qu'américains suivent des cours de sciences, mais ils s'intéressent moins aux cours de sciences supérieurs et aux carrières scientifiques.

Les conclusions formulées jusqu'à présent sur les attitudes envers les sciences à l'école s'avèrent assez consistantes, mais il reste des questions très pertinentes à poser. Par exemple, pourquoi les élèves semblent-ils aimer si peu les sciences à l'école, en particulier la physique, et pourquoi le taux de décrocheurs aux cours de sciences est-il si élevé ? La plupart des constatations dont nous avons fait état jusqu'ici traitent de la situation, mais ne se penchent pas sur ses causes.

• Les enseignants en mathématiques et en sciences

L'information détaillée que l'on peut tirer des études existantes sur les professeurs de sciences et de mathématiques est rare. Un rapport canadien (16) et deux évaluations américaines (8 et 10) indiquent que les enseignants nord-américains en sciences sont mieux préparés qu'auparavant, mais que le nombre de professeurs de physique est encore insuffisant. La plupart des enseignants en sciences du secondaire possèdent une spécialisation dans ce domaine. Au primaire, bon nombre de professeurs n'ont aucune formation en sciences même si la plupart d'entre eux sont obligés d'inclure les sciences dans leur programme d'enseignement. Les études portant sur les programmes et les activités en classe font ressortir davantage d'information sur ces enseignants.

• Les activités de sciences et de mathématiques en classe

Les constatations relevées sur les activités réalisées en sciences et en mathématiques peuvent se répartir en deux catégories : le temps consacré à ces deux domaines dans l'ensemble du programme d'études et les divers types d'activités prévus.

Dans le premier cas, il apparaît clairement que le temps consacré aux sciences et aux mathématiques est proportionnel à la réussite des élèves dans ces domaines. Voilà pourquoi il n'est pas surprenant de constater que les élèves chinois et japonais passent beaucoup plus de temps à étudier les sciences et les mathématiques à l'école que les enfants nord-américains (4) et qu'ils font aussi beaucoup plus de devoirs de mathématiques et de sciences que les jeunes des autres pays.

Une importante étude américaine (8) a établi que les deux tiers des enseignants américains de 3e année passent moins de temps à enseigner les sciences qu'à maintenir la discipline et que 11 % d'entre eux ne donnent aucun cours de sciences. Le tiers de tous les élèves du primaire aux États-Unis ne fait pas de devoirs en sciences et, en 1986, seulement la moitié des élèves de 7e et de 11e année a reçu plus de trois heures de cours de sciences par semaine. Si 94 % des élèves de 7e année ont eu des cours de sciences en 1986, cette proportion tombe à 58 % en 11e année. À ce niveau, peu d'élèves ont fréquenté des cours supérieurs en chimie ou en physique. Le temps consacré aux sciences est beaucoup moins élevé en Amérique du Nord que dans les pays où les élèves réussissent le mieux.

Les recherches sur les activités scientifiques et mathématiques réalisées en classe concernent surtout l'Amérique du Nord. Il semble que les méthodes d'enseignement utilisées soient de type très traditionnel. Une étude internationale (3) et une enquête américaine (6) indiquent que les classes de mathématiques consistent d'ordinaire en cours magistraux, en travail personnel au pupitre et en exercices tirés du manuel. L'utilisation d'ordinateurs ou de calculatrices est assez rare. Les travaux collectifs, les projets ou les activités innovatrices ne sont pas courants. La même étude internationale souligne qu'il n'y a pas assez d'activités pratiques dans la plupart des cours de sciences. Une autre étude révèle qu'aux États-Unis, peu d'efforts ont été consacrés au renouvellement du contenu des cours ou des méthodes et qu'il reste beaucoup d'améliorations à apporter aux activités réalisées dans le cadre des cours de sciences.

• Résumé

Le portrait global que tracent ces études dépeint une situation où les élèves nord-américains réussissent moins bien en sciences et en mathématiques, lors des épreuves, que les Japonais, les Chinois, les Coréens et de nombreux Européens. Dans l'ensemble, leur attitude envers les sciences ou les mathématiques n'est pas positive et ils ne s'inscrivent que rarement à des cours supérieurs dans l'une ou l'autre discipline. À l'école, ils consacrent moins de temps aux sciences et au mathématiques que les élèves des autres pays, même si leurs professeurs ne maîtrisent pas moins bien les sujets de cette nature ou ne sont pas moins compétents que ceux des autres pays. De plus, les activités réalisées en classe dans les deux disciplines semblent ennuyeuses et démodées.

Il est manifeste que tout le domaine de l'enseignement des sciences et des mathématiques a un besoin urgent, en Amérique du Nord, d'être renouvelé. Ce renouvellement est déjà commencé. La deuxième partie du présent document examine quelques-unes des manières par lesquelles le processus de renouvellement est en train de se réaliser.

B Les mesures prises en vue de renouveler l'enseignement des sciences et des mathématiques

Cette partie regroupe de façon systématique bon nombre des innovations et des mesures récentes mises de l'avant, en Amérique du Nord et ailleurs dans le monde, en vue de renouveler l'enseignement des sciences et des mathématiques.

Il semblerait raisonnable de supposer que les observations notées dans un si grand nombre d'études et d'enquêtes réalisées au cours des dix dernières années aient entraîné le déploiement d'efforts énergiques pour corriger la situation en apparence mauvaise de l'enseignement des sciences et des mathématiques en Amérique du Nord. En fait, les efforts accomplis remontent bien avant : dès le milieu des années 50, les autorités américaines compétentes commençaient à chercher des moyens d'améliorer l'enseignement des sciences et des mathématiques dans les écoles.

Au cours des 20 dernières années, des sommes d'argent considérables ont été investies pour rendre l'enseignement des sciences et des mathématiques compétitif au plan international et pour suivre les nouvelles tendances, notamment en ce qui concerne les méthodes d'enseignement et les aspects les plus importants sur lesquels mettre l'accent.

Au Canada, il n'y a pas eu d'effort national comparable. Ce sont les provinces qui ont surtout agi. Au plan national, l'intérêt s'est accru ces derniers temps, mais aucun investissement significatif n'a été réalisé. L'étude majeure réalisée par le Conseil des sciences du Canada de 1980 à 1984 (5) a suscité nombre d'initiatives locales. En 1987, le gouvernement fédéral a mis sur pied un programme de bourses afin de promouvoir l'étude des sciences au niveau postsecondaire.

• Les indicateurs relatifs à l'enseignement des sciences et des mathématiques

Aux États-Unis, des efforts considérables sont actuellement déployés afin de systématiser et de rationaliser la grande quantité d'information disponible et les données qui sont actuellement recueillies sur l'enseignement des sciences et des mathématiques. Le National Research Council de la National Academy of Sciences (18) a proposé de recueillir de l'information sur plusieurs de ces aspects :

l'apprentissage des élèves, les connaissances scientifiques et mathématiques des adultes, les inscriptions et le temps consacré aux sciences et aux mathématiques à tous les cycles du secondaire, les activités de sciences et de mathématiques en classe, les connaissances et la formation des enseignants dans ces domaines, leur rémunération et, enfin, le contenu des programmes d'études, le matériel et les ressources. Le conseil a proposé un cycle d'évaluation s'étendant sur quatre ans et une grille d'analyse tenant compte du lieu, de la race, du sexe et d'autres facteurs semblables.

De même, le Council of Chief State School Officers (19) (déjà mentionné plus haut) est en train de réaliser un projet relatif aux indicateurs afin de mettre au point une méthode de comparaison des statistiques et autres données sur les sciences et les mathématiques. L'information recueillie ou prévue concerne la réussite, les statistiques d'inscription, l'affectation des enseignants par matière et par diplôme, l'offre et la demande d'enseignants et leur recrutement. De nombreux états américains font déjà subir régulièrement des épreuves en sciences et en mathématiques aux élèves. Le U.S. Council of Chief State School Officers et l'Education Commission of the States signalent que plus d'une quarantaine d'états ont des programmes d'évaluation du succès des élèves dans ces disciplines. Le résultat de ces activités de cueillette devrait être la mise sur pied d'une solide base de données sur l'évolution de l'enseignement des sciences et des mathématiques.

Au Canada, la définition d'indicateurs sur l'enseignement en général (par opposition à l'enseignement des sciences) en est encore à ses premiers balbutiements ; elle progresse sous l'égide du Conseil des ministres de l'Éducation du Canada. Malgré leur importance manifeste pour l'entreprise scientifique au Canada, les indicateurs scientifiques utilisés excluent traditionnellement les statistiques sur l'enseignement des sciences au primaire et au secondaire. Ainsi, certains indices révèlent que le nombre d'élèves qui optent pour des cours de physique au secondaire constitue le facteur restrictif le plus significatif du nombre futur d'étudiants inscrits aux programmes universitaires de sciences et de génie. Pourtant, aucun organisme national ou provincial n'a encore montré d'intérêt réel pour l'étude de ces données.

• Les objectifs de l'enseignement des sciences et des mathématiques

Jusqu'à maintenant, les activités réalisées ont en quelque sorte été passives, c'est-à-dire qu'elles ne constituent pas des étapes concrètes d'apprentissage, mais plutôt des comptes rendus d'expériences venant confirmer les programmes. Toutefois, la définition d'objectifs et de buts nouveaux pour l'enseignement des sciences et des mathématiques est un signe majeur de changement. Aux États-Unis, l'Office of Science and Technology Education de l'Association américaine pour l'avancement des sciences a lancé un vaste projet de redéfinition des grands objectifs de l'enseignement des sciences. Le « Projet 2061 » (20) cherche à prédire la situation de la science et de la technologie en l'an 2061 (année où la comète de Halley s'approchera de nouveau de la terre) et à définir des objectifs d'enseignement afin de s'y préparer. Les buts et objectifs qui seront ainsi définis devront tracer la route à suivre pour l'enseignement des sciences jusqu'au milieu du 21e siècle.

Le même organisme de l'Association américaine pour l'avancement des sciences parraine également un autre projet qui vise à favoriser le renouvellement de l'enseignement des sciences. Il s'agit du Forum national sur la science à l'école (National Forum on School Science) qui réunit régulièrement des théoriciens et des praticiens afin de leur permettre de partager et de comparer leurs idées et leurs expériences. C'est manifestement un événement périodique important.

Au Canada, le gouvernement de la Saskatchewan, dont la politique en matière d'éducation se fonde sur le concept de culture scientifique et sur la compréhension, les aptitudes, les procédés, les valeurs et les attitudes connexes qui en découlent (21), a déployé des efforts importants pour dresser un plan global de réforme de l'enseignement des sciences.

• Les modifications à l'orientation des programmes d'études

En pratique, ce sont les conditions de délivrance des diplômes et d'admission au collège qui régissent le plus profondément la réalité de l'enseignement des sciences et des mathématiques au secondaire. Cette tendance est très claire, tant aux États-Unis qu'au Canada. Selon l'Education Commission of the States (22), le nombre de cours obligatoires de sciences et de mathématiques pour l'obtention

du diplôme de fin d'études secondaires tend à augmenter. En outre, le niveau des cours est en voie d'être haussé et un certain nombre de cours plus avancés sont offerts. Ce resserrement des exigences se fait également sentir au Canada ; il s'agit d'une réaction au cadre plutôt large de délivrance des diplômes qui a prévalu au cours des années 60 et 70. L'effet indéniable de ce resserrement sera d'exposer un nombre accru d'élèves à l'étude des sciences et des mathématiques, ce qui, il faut l'espérer, devrait susciter un intérêt accru.

L'augmentation du nombre de cours obligatoires s'accompagne d'un mouvement de renouvellement des programmes qui se manifeste partout en Amérique du Nord. À de rares exceptions près, les états américains et les provinces canadiennes sont en train de réviser ou ont déjà effectué des révisions majeures aux lignes directrices des programmes et au contenu des cours. L'Education Commission of the States recueille les données portant sur les lignes directrices déterminées par les divers états américains sur les programmes. Elle note une tendance à encourager la réflexion, le jugement, la logique et d'autres habitudes intellectuelles plus rigoureuses dans l'enseignement des sciences et des mathématiques et, bien entendu, à augmenter le nombre de cours de sciences et de mathématiques nécessaire pour obtenir le diplôme. Les principales préoccupations relevées concernent l'amélioration du contenu des cours de sciences, surtout dans des domaines comme la physique et la science au niveau fondamental, ainsi que le nombre d'enseignants de sciences qualifiés et compétents.

Au Québec, le ministre de l'Éducation a demandé un avis spécial sur la question au Conseil supérieur de l'éducation. Dans son rapport, le Conseil exprime son opinion à l'effet que les programmes en sciences et mathématiques sont fondamentalement solides quoique leur réalisation laisse à désirer (23). Cependant, il a insisté sur de nombreux ajustements qui s'imposeraient pour améliorer davantage le système d'enseignement des sciences et des mathématiques. On peut mentionner particulièrement à cet égard le rééquilibrage, la consolidation et l'apport de modifications importantes à la séquence des cours obligatoires de mathématiques; une plus grande harmonisation des ordres secondaire et collégial, et plus particulièrement un «vigoureux élagage» de la liste des cours préalables en mathématiques et en sciences de la nature; et la diversification des approches et des pratiques pédagogiques.

En Colombie-Britannique, une commission royale d'enquête a été mise sur pied spécifiquement sur l'enseignement des sciences et a mené à la mise au point d'un tronc commun de sciences allant de la maternelle à la 12^{e} année (dernière année d'études dans cette province). L'un des nouveaux cours préparés est le cours de science et de technologie 11, qui associe étroitement science, technologie et société, conformément aux dernières tendances de l'enseignement des sciences.

En Alberta, une révision des programmes de sciences dans les écoles a également mené à l'intégration des volets science, technologie et société. Une autre innovation, qui se manifeste ailleurs, est la conception de cours de sciences spécialement pour les élèves qui n'envisagent pas d'étudier les sciences après le secondaire.

L'Ontario a lancé récemment un programme spécial (auquel elle a consacré 3 millions de dollars) en vue de renouveler l'enseignement des sciences au primaire et au premier cycle du secondaire. Ce programme implique l'élaboration d'une nouvelle orientation et la définition de lignes directrices pour le programme d'études, ainsi que l'adoption de mesures concernant le matériel scientifique et la formation des enseignants (24).

Les modifications apportées aux programmes d'études aux États-Unis et au Canada sont très significatives. Elles convergent vers un apprentissage beaucoup plus systématique que maintenant des mathématiques et des sciences à l'école et changent la nature d'une grande partie de la matière enseignée. Le but visé est de rendre les sciences plus pertinentes pour les élèves, quelles que soient leurs aptitudes, et de faire le lien avec les réalités de leur vie. Beaucoup d'efforts sont actuellement déployés pour éloigner l'enseignement des sciences de la seule optique de préparation à l'apprentissage des sciences aux niveaux supérieurs en faveur d'un enseignement significatif et pertinent pour chaque enfant et chaque adolescent.

• Les mesures de renouveau en provenance de l'école

Une suite logique à la concentration des programmes d'études en sciences est la création d'écoles où les sciences et les mathématiques constituent le cœur de tout le programme. L'Education Commission of the States (22) signale que des écoles à vocation scientifique ou mathématique existent déjà ou sont en voie d'être implantées dans une vingtaine d'états américains ; certaines profitent du soutien d'organismes privés. Pour pouvoir fréquenter ces écoles, certains élèves doivent s'éloigner de leur lieu de résidence. L'admission à ces écoles se fait souvent par voie de concours et les programmes offerts sont de niveaux supérieur et enrichi. Des cours d'été offrent des possibilités similaires, mais à court terme. Ils peuvent rejoindre une population beaucoup plus importante et n'obligent pas les élèves à vivre longtemps loin de chez eux.

Quelques écoles et programmes semblables existent aussi au Canada. Dans la région de Québec, la Commission scolaire des Découvreurs vient d'inaugurer une école primaire du secteur public où l'accent est mis sur l'enseignement des sciences, l'école Fernand-Seguin. Dans la région de Toronto, l'école secondaire Marc Garneau met nettement l'accent sur les mathématiques, les sciences et la technologie. Dans plusieurs autres villes, des écoles secondaires offrent des programmes d'études enrichies qui comprennent ces disciplines. La création d'écoles secondaires à vocation scientifique n'a toutefois pas retenu une attention importante au Canada. En fait, l'idée n'a pas été bien reçue, en général, lorsque le Conseil des sciences (5) l'a proposée en 1984.

- **Les manuels et le matériel didactique**

La conception de matériel didactique a été au cœur d'une bonne partie des interventions de renouvellement de l'enseignement des sciences et des mathématiques. Les éditeurs produisent du matériel intéressant, surtout écrit, visant à traduire les tendances actuelles en science et en technologie et l'évolution des techniques d'enseignement. L'enseignement des sciences et des mathématiques repose en grande partie sur l'utilisation de manuels. Il y a lieu de croire qu'ils continueront d'avoir un effet important sur l'enseignement. Il existe néanmoins un grand besoin de matériel d'un autre type, qui n'est pas vraiment satisfait. Le matériel visuel, c'est-à-dire les films et les vidéos, ainsi que les documents de référence et d'approfondissement, les trousses et le matériel d'activités restent à mettre au point afin d'animer les cours de science.

Le gouvernement canadien a créé un programme appelé « Sciences et culture Canada » et a effectué une campagne de sensibilisation du public aux sciences et à la technologie, qui ont financé la production de matériel pertinent et contemporain. On pourrait donner en exemple les brochures intitulées *La technologie et l'innovation dans l'industrie canadienne* (25). Ces plaquettes, publiées en français et en anglais, décrivent de façon précise certaines initiatives canadiennes dans des domaines comme l'aquaculture et les aéronefs fonctionnant à l'énergie solaire et proposent des façons d'intégrer la discussion sur ces innovations aux cours de sciences et société. Tous les ministères de l'Éducation, sauf celui du Québec, ont accepté de les utiliser dans les écoles secondaires.

Le ministère ontarien de l'Éducation a accompli un travail précieux à cet égard dans ses efforts de renouvellement des sciences au primaire et au premier

cycle du secondaire. Il encourage la production de trousses de sciences et a mis au point un plan d'élaboration de matériel didactique. Il dispose également de fonds pour la préparation de vidéos par TV-Ontario, le réseau provincial de télévision éducative, et de logiciels d'enseignement des sciences. Des efforts sont donc déployés pour développer du matériel didactique, des ressources, des moyens audiovisuels, des logiciels et des didacticiels, mais il ne s'agit que d'un début : les possibilités dépassent de loin les réalisations actuelles.

• Le renouvellement du personnel enseignant

Nous en arrivons à la question des mesures touchant les professeurs de sciences et de mathématiques. La plupart des pays font face de bien des manières différentes au problème commun de s'assurer les services d'un nombre adéquat d'enseignants en sciences et en mathématiques qui connaissent à la fois bien leur matière et qui soient en même temps bien préparés à enseigner selon le niveau de leurs élèves.

L'Education Commission of the States (22) signale que de nombreuses solutions nouvelles sont à l'essai dans diverses parties des États-Unis. Plusieurs états offrent des primes salariales aux professeurs de sciences et de mathématiques et leur procurent des prêts et des bourses afin d'améliorer leur connaissance de ces disciplines ou leur technique d'enseignement. L'un des états va même jusqu'à utiliser les recettes de sa loterie pour financer ce recyclage. Vingt-cinq états offrent des prêts pour compléter la formation des futurs maîtres avant qu'ils n'enseignent les sciences et les mathématiques et au moins un recours à la télévision pour permettre aux enseignants des régions éloignées de se tenir à jour. En plus de ces mesures extraordinaires, certains états reconnaissent la formation et l'expérience acquises de façon non académique des futurs enseignants, tandis que d'autres recrutent des professeurs à l'étranger, y compris en Allemagne de l'Ouest.

D'autres initiatives prises aux États-Unis portent, par exemple, sur des programmes visant à donner aux enseignants en sciences de New York, l'expérience de la science dans le monde du travail et sur la formation d'un réseau de conseillers pour amener les meilleurs enseignants à partager avec les autres leurs aptitudes et leurs expériences. La tendance de l'ensemble des programmes américains vise deux objectifs : offrir aux enseignants qui ne se sentent pas à l'aise dans ces disciplines des cours sur la matière enseignée et favoriser

l'acquisition par les enseignants de la méthodologie qui convient le mieux à la matière enseignée et aux élèves avec qui ils travaillent.

Les cours destinés aux enseignants canadiens suivent une voie similaire. L'Ontario a mis sur pied un comité consultatif sur la formation des maîtres et le recyclage des enseignants en sciences au primaire; elle a également créé un programme de cours de qualification supplémentaire à l'intention de ces enseignants. Les commissions scolaires locales et les fédérations d'enseignants sont invitées à accorder à l'amélioration et au perfectionnement professionnel des enseignants en sciences et en mathématiques une priorité élevée.

Le Nouveau-Brunswick recourt à des téléconférences dans le cadre d'un projet visant, d'une part, à aider les professeurs de sciences du primaire et, d'autre part, à offrir aux enseignants du secondaire un meilleur contenu scientifique. Les cours de fin de semaine et d'été organisés au Nouveau-Brunswick pour les professeurs de sciences sont caractéristiques de ce qui se fait dans de nombreuses provinces.

- **L'influence du secteur privé**

Les efforts visant à renouveler l'enseignement des sciences et des mathématiques impliquent également toute une gamme de coalitions ou d'alliances stratégiques ayant pour but de rallier, d'une part, des organismes étrangers au monde de l'enseignement comme l'industrie, le commerce, l'État, les chercheurs, etc. et, d'autre part, le monde de l'enseignement. Plutôt que d'organiser des colloques et des discussions, la plupart des groupes ainsi formés mettent en application des programmes pratiques précis.

Ainsi, aux États-Unis, la Triangle Coalition est une alliance nationale de scientifiques, d'industriels et d'enseignants qui désirent soutenir l'amélioration de l'enseignement des sciences et des mathématiques. Les groupes de travail qui la composent formulent des recommandations concernant, par exemple, la technologie de l'enseignement et établissent, au niveau local, des réseaux, des groupes d'aide aux enseignants et des alliances école-industrie.

Au Canada, la plupart des activités conjointes école-industrie se déroulent au palier provincial. En Colombie-Britannique, l'Association for the Advancement of Science Education anime un réseau d'enseignement des sciences au primaire et publie un bulletin. Dans la même province, le ministère de l'Enseignement supérieur, de la Science et de la Technologie dispose d'un

programme appelé « Scientist in the Schools » visant à amener en classe des scientifiques de l'industrie, des laboratoires et des universités. Le British Columbia Science Council a également mis sur pied un groupe de travail pour trouver des moyens d'appuyer l'enseignement des sciences dans les écoles. À ce chapitre, cette province affiche un leadership extraordinaire.

Ailleurs au Canada, le secteur privé prend une certaine part à l'enseignement des sciences. La compagnie Northern Telecom décerne des prix aux élèves, et la fondation SEEDS utilise des dons du secteur énergétique pour produire un excellent matériel didactique et financer un programme de perfectionnement des professeurs de sciences qui connaît beaucoup de succès. À part ces quelques initiatives, le secteur privé canadien fait peu pour l'enseignement des sciences et des mathématiques. L'Association canadienne de technologie de pointe et la Chambre de commerce du Canada ont montré un certain intérêt, mais les deux organismes ne sont pas encore passés à l'action, du moins jusqu'à présent.

• Les programmes à l'intention des élèves

Aux États-Unis et au Canada, de nombreux programmes reconnaissent les mérites des élèves exceptionnels en sciences et en mathématiques, les encouragent et les aident à poursuivre leurs études. L'Education Commission of the States (22) a répertorié des concours scientifiques, des jeux questionnaires et des épreuves couronnés de prix spéciaux. Les expositions et les jeux scientifiques posent un défi aux élèves en leur permettant de sortir du cadre scolaire et en encourageant la réalisation de projets personnels ou l'application de connaissances apprises en classe dans de nouveaux contextes. Le monde des affaires et de l'industrie accorde des prix à des élèves exceptionnels ; il existe aussi des programmes pour aider les jeunes à prendre part à des ateliers, à des camps, à des cours coopératifs, etc.

Au Canada, un programme fédéral de bourses permet d'offrir de l'argent aux étudiants qui choisissent d'étudier les sciences à l'université. Ce programme ne fonctionne toutefois pas à plein régime à cause, entre autres, de problèmes de juridiction fédérale-provinciale.

Aux États-Unis, des programmes spéciaux d'enseignement des sciences et des mathématiques s'adressent aux minorités ethniques. L'Education Commission for the States recense, par exemple, des olympiades pour les autochtones, des ateliers de sciences et de mathématiques destinés aux femmes et des

cours d'été pour les handicapés et les minorités, des groupes qui, traditionnellement, ne sont pas bien représentés dans les communautés scientifique et mathématique.

Conclusion

Le Canada et les États-Unis sont des modèles de contraste quant aux moyens à prendre pour réaliser un objectif national comme le renouvellement de l'enseignement des sciences et des mathématiques. D'un côté, la situation des Américains semble pire que celle des Canadiens : leurs élèves réussissent beaucoup moins bien aux examens, leurs enseignants sont souvent moins qualifiés et les problèmes qui assaillent leurs écoles — surtout dans les villes — sont plus graves. Pourtant, la volonté et l'engagement manifestés au plan national en vue d'améliorer la situation sont nettement supérieurs aux attitudes plutôt suffisantes et indifférentes qui se font sentir au Canada, dans les milieux officiels, du moins.

Aux États-Unis, l'argent qui est actuellement consacré aux programmes visant à renouveler l'enseignement des sciences et des mathématiques dépasse, uniquement au niveau fédéral, les 260 millions de dollars, dont la moitié est destinée aux écoles de district, partout au pays. L'autre moitié va à la National Science Foundation, afin d'appuyer les programmes d'enseignement des sciences et des mathématiques au niveau pré-collégial. L'industrie privée contribue de manière importante à cet enseignement, tant directement (par exemple, les dons de micro-ordinateurs effectués par IBM pour aider à la formation des enseignants), qu'indirectement (la mise sur pied de plus de 80 alliances locales pour appuyer l'amélioration de l'enseignement des sciences et des mathématiques, comme la Colorado Alliance for Science).

Au Canada, à l'opposé, et ce, malgré les déclarations du premier ministre lors de la conférence nationale de janvier 1988 sur la technologie et l'innovation concernant l'importance de l'enseignement des sciences et des mathématiques dans les écoles, l'argent affecté par le gouvernement fédéral à cet enseignement au primaire et au secondaire s'élève à exactement zéro dollar. Une certaine somme d'argent atteint de temps à autre le réseau scolaire par l'entremise du modeste programme de « Science et culture Canada » et, indirectement, du Conseil de recherches en sciences sociales et humaines (CRSSH) sous forme de subventions de recherche sur l'enseignement des sciences et des mathématiques.

Le secteur privé ne fait pas mieux. En dépit des fréquentes critiques sur la situation de l'enseignement des sciences et des mathématiques dans les écoles, le secteur privé canadien ne fait presque rien comparativement au secteur privé américain. Il y a, bien entendu, des exceptions notables, comme Shell Canada, Northern Telecom, Apple Canada et quelques autres. Toutefois, lorsqu'on lui a donné l'occasion de poser un geste significatif en mettant sur pied une alliance

canadienne pour appuyer l'enseignement des sciences et des mathématiques, l'Association canadienne de technologie de pointe a délibéré pendant au moins un an et a décidé que ses membres, un peu partout au pays, « n'étaient pas très intéressés ».

Au plan provincial, il existe une tension naturelle entre les autorités du monde de l'enseignement, qui tendent à considérer les sciences et les mathématiques comme « simplement deux des disciplines figurant au programme », et la communauté scientifique dont l'influence sur le réseau d'enseignement provincial est très limitée. Au mieux, le résultat est une impasse. À peu près rien n'est fait. Parfois, une hostilité directe et ouverte peut se faire sentir comme celle qui s'est manifestée récemment en Alberta alors que la faculté des sciences de l'université de l'Alberta et le ministre de l'Éducation se sont affrontés publiquement dans la presse sur la qualité des programmes d'enseignement des sciences de la province.

Le consensus canadien qui existe actuellement semble se borner à reconnaître que l'enseignement des sciences et des mathématiques a besoin d'un souffle nouveau, mais que le problème n'est pas assez grave pour justifier le bouleversement du délicat équilibre des juridictions fédérale et provinciale, le monde scientifique et celui de l'enseignement ou entre le secteur public et le secteur privé. Ceux et celles qui désirent effectuer des changements sont donc laissés à eux-mêmes et cantonnés au niveau local. Bon nombre des projets entrepris par certaines écoles et certains enseignants sont sous-financés et sont rarement connus. Leur impact se limite donc à l'endroit où ils se déroulent et les leçons qui s'en dégagent sont rarement diffusées dans la profession.

Les opinions et l'analyse qui précèdent soulèvent un certain nombre de questions susceptibles d'alimenter une discussion à venir. Plus particulièrement, les points suivants devraient faire l'objet d'un débat immédiat à tous les paliers au Canada.

1. **Dans quelle mesure un réseau d'enseignement visant l'acquisition des connaissances scientifiques de base par tous peut-il également permettre l'essor de l'excellence scientifique et technologique ? Comment peut-on y parvenir ?**

2. **Quels sont les critères de qualité de l'enseignement des sciences et des mathématiques ? Comment devrait-on mesurer régulièrement la qualité de cet enseignement ?**

3. **Comment l'appui au renouvellement de l'enseignement des sciences et des mathématiques peut-il être accru ? D'où devrait venir cet appui ? Est-ce un besoin urgent ?**

4. Comment peut-on s'assurer que l'enseignement actuel des sciences et des mathématiques à l'université n'engendre pas de nouveaux problèmes pour les sciences et les mathématiques aux autres niveaux scolaires ?

5. Quelles incitations existe-t-il pour motiver les élèves à atteindre l'excellence en sciences et en mathématiques ? La société attache-t-elle de la valeur à cette excellence ?

Bibliographie

1. Curtis McKnight et al., *The Underachieving Curriculum: Assessing U.S. Mathematics from an International Perspective* (Champaign, Ill.: Stipes Publishing Company, 1987).

2. International Evaluation Association, *Science Achievement in Seventeen Countries: A Preliminary Report* (Oxford: Pergamon, 1988).

3. Archie Lapointe et al., *A World of Differences: An International Assessment of Mathematics and Science* (Princeton, N.J.: Educational Testing Service, 1989).

4. Harold W. Stevenson, Shin-Ying Lee, and James E. Stigler, «Mathematics Achievement of Chinese, Japanese and American Children», *Science, 231* (14 février 1986), p. 693-699.

5. Conseil des sciences du Canada, *À l'école des sciences: la jeunesse canadienne face à son avenir*, Rapport 36 (Ottawa: Approvisionnements et Services Canada, 1984), et G.W.F. Orpwood et J.-P. Souque et al., *Enseignement des sciences dans les écoles canadiennes, étude de documentation* n° 52 (3 volumes), Conseil des Sciences du Canada (Ottawa: Approvisionnements et Services Canada, 1984).

6. National Assessment of Educational Progress, *The Mathematics Report Card: Are We Measuring Up ?* (Princeton, N.J.: Educational Testing Service, 1988).

7. National Assessment of Educational Progress, *Computer Competence: The First National Assessment* (Princeton, N.J.: Educational Testing Service, avril 1988).

8. National Assessment of Educational Progress, *The Science Report Card: Elements of Risk and Recovery* (Princeton, N.J.: Educational Testing Service, 1988).

9. Iris Weiss, *Report of the 1985-86 National Survey of Science and Mathematics Education*, Research Triangle Institute, 1987.

10. Michael Neuschatz et Maude Covalt, *Physics in the High Schools, Findings from the 1986-87 Nationwide Survey of Secondary School Teachers of Physics* (New York: American Institute of Physics, 1988).

11. U.S. Congress, *Office of Technology Assessment, Educating Scientists and Engineers: Grade School to Grad School*, OTA SET-377 (Washington, D.C.: Government Printing Office, 1988).

12. *British Columbia Science Assessment, 1986, Summary Report* (Victoria: Ministry of Education, 1986).

13. *Alberta Diploma Examinations Program: Provincial Report*, juin 1988, Administration (Edmonton: Alberta Education, 1988).

14. Paul Hart, *Science for Saskatchewan Schools: Field Study Report and Science for Saskatchewan Schools: A Review of Research Literature, Analysis and Recommandations* (Regina: Saskatchewan Instructional Development and Research Unit, 1987).

15. *Manitoba Science Assessment, 1986, Final Report and Summary* Report (Winnipeg: Manitoba Education, 1986).

16. F. Michael Connelly, *Ontario Science Education Report Card: Canadian National Comparisons* (Toronto: ministère ontarien de l'Éducation, 1987).

17. Gilles Dussault, *L'enseignement des sciences dans les écoles secondaires du Québec: Bilan, recommandations et interrogations* (Montréal: Sommet québécois de la technologie, 1988). Le rapport Dussault a été justement critiqué pour son traitement des élèves de 5e secondaire. Il faut rappeler que les élèves de fin de secondaire au Québec ont reçu onze années de scolarité, tandis que ceux des autres pays en ont généralement reçu douze. De plus, les élèves québécois ne sont pas encore spécialisés à ce niveau; ce n'est pas toujours le cas dans d'autres pays. Ces deux éléments rendent certaines comparaisons problématiques.

18. Committee on Indicators of Precollege Science and Mathematics Education, *Indicators of Precollege Education in Science and Mathematics: A Preliminary Review (1985)* et *Improving Indicators of the Quality of Science and Mathematics Education in Grades K-12*, (1988) (Washington: National Research Council of the Academy of Sciences).

19. Il existe trois rapports de projet: 1) *State Education Indicators on Science & Math, Results of a 50-State Inventory*; 2) *State Policies Related to Science & Mathematics Education*; et 3) *Indicators of Science & Mathematics Education: Providing Tools for State Policymakers*. Il est possible d'en obtenir un exemplaire, pour la somme de 2 $ chacun, payable d'avance, en s'adressant à Rolf Blank, Director, Science/Math Indicators Project, Council of Chief State School Officers, 400 N. Capitol Street, N.W., Washington, D.C. 20001.

20. American Association for the Advancement of Science, *Science for All Americans, Report of phase I of Project 2061* (Washington, D.C.: AAAS, 1989).

21. Voir Saskatchewan Education, *Science Education Curriculum Development Newsletter*, Regina, janvier 1988.

22. Education Commission of the States, *State Initiatives to Improve Science and Mathematics Education* (Denver, Co.: E.C.S., 1987).

23. Conseil supérieur de l'éducation, *Les Sciences de la nature et la mathématique au deuxième cycle du secondaire*, Québec, janvier 1989. Tout récemment, le Conseil supérieur de l'éducation a publié un nouvel avis intitulé *Améliorer l'éducation scientifique sans compromettre l'orientation des élèves. Les sciences de la nature et la mathématique au deuxième cycle du secondaire*, Avis au ministre de l'Éducation et ministre de l'Enseignement supérieur et de la Science, Québec, novembre 1989. Le ton y est plus dur, et de «sérieuses réserves» sont exprimées concernant certaines des plus récentes modifications suggérées par le ministère. Rappelant les «enjeux fondamentaux» en cause dans le cas de l'enseignement secondaire, le Conseil supérieur suggère que la réflexion nécessaire dans ce dossier «pourrait même conduire à une révision globale du régime pédagogique».

24. Ontario, *Science in Primary and Junior Education* (Toronto: ministère de l'Éducation de l'Ontario, 1986).

25. Graham Orpwood, Douglas Wrigglesworth et Tim Fielding, *La technologie et l'innovation dans l'industrie canadienne* (Ottawa: Ministère d'État à la Science et à la Technologie et Orpwood Associates, 1989).

Science and Mathematics Education in North America:

ADVANCE OR DECLINE ?

- DISCUSSION PAPER -

by

Graham Orpwood

Conseil de la science et de la technologie

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Preface

This discussion paper has been prepared in fulfillment of a contract with the Conseil de la science et de la technologie to review recent studies and initiatives in the fields of mathematics and science education in North America.

The study's terms of reference recognize, as the *problématique* of the study, that science and mathematics education at the primary and secondary levels are the objects of much concern, assessment, and renewal in North America today. And in order to set the discussion of these issues in Québec in a broader North American context, the study has been focused on two principal objectives:

1. To review the most significant studies of science and mathematics education at the primary and secondary levels which have been undertaken in the past few years and to identify their principal findings;

2. To describe some of the initiatives undertaken in North America whose purposes have been to improve the state of science and mathematics education at the elementary and secondary levels.

The first phase of the study produced a detailed report comprising summaries of a large number of studies and reports published within the past five years. It was divided into two parts, corresponding to the two objectives noted above: assessments of science and mathematics education; and initiatives to improve science and mathematics education. Part A covered four types of assessment: international studies; Canadian nationwide studies; American national studies; and Provincial studies. Part B was similarly subdivided into U.S. national initiatives; U.S. state initiatives; Canadian nationwide initiatives; and Provincial initiatives.

The present paper is different in form and also in purpose. While the report provided the interested reader with a systematic account of the major reports of the state of math and science education in North America, this paper provides an analysis of these reports, issue by issue. It is intended to provoke discussion about those aspects of science and mathematics education that have attracted the most attention by organizations and researchers and those aspects of policy and practice on which initiatives for change are being focussed.

The reader may find that both the report and the discussion paper are best read together, since the paper draws directly on the more detailed report. However, the discussion paper and the report are also self-contained and may also be read on their own.

Introduction

Today, perhaps more than ever before, science, technology and mathematics are crucial to almost all human enterprises. Most of the burning issues of the age have a scientific element, whether it be the environment, the capacity of missiles, or the viability of the fetus. Indeed, technological innovation in communications has led to fundamental shifts in more than one field. For example, face-to-face trading in local and even national stock exchanges is becoming less and less important in a world where computers permit global trading at the touch of a button. And the fact that satellite picture transmissions enable us to see demonstrations, riots and even battles as they take place means that we do not have to rely on the "official" news of other nations to know what is happening there. This in turn can influence what actually takes place.

The tremendous impact of computer and other technologies on the workplace leads to the increasing influence of science and technology on industry and commerce, which are now in the throes of an upheaval as significant as the industrial revolution. Throughout industry, the exploitation of raw materials is giving way in relative importance to the use of information technologies and to the development of other new applications of scientific knowledge and skills.

As a result, there has been in recent years renewed interest and concern for science and mathematics education as society becomes aware of these fundamental changes taking place in the global economy in the final decades of the twentieth century. In the future, all informed citizens will need a degree of scientific and technological literacy, even though they do not have the detailed understanding of experts.

Clearly, a vital factor in any economy will be how its citizens can face the challenge of these changes. In other words, do they have the skills, knowledge and inventiveness that are crucial to keeping up with the rest of the world? The popular feeling, expressed in many an editorial and article, is that we in North America are far behind the rest of the world as regards our young people's preparedness in these respects. It is generally held, too, that this situation is getting progressively worse. Many studies of science and mathematics education have been undertaken in the last five or ten years with a view to assessing the true status of students and school systems in respect to these questions and many plans, strategies and initiatives have been tried. Accordingly, this paper is divided into two parts, the first outlining the themes and conclusions of the many studies of the state of mathematics and science education, and the second describing some of the wide array of initiatives being undertaken with a view to the renewal of policy and practice in these fields.

A Studies of Mathematics and Science Education

The studies on which this paper and its companion report are based are fully referenced in the bibliography. In an attempt to make this discussion as accessible as possible, footnotes are not used. Rather, numbers in parentheses refer the reader to the appropriate item in the bibliography.

International studies include two sponsored by the International Association for the Evaluation of Educational Achievement: the Second International Mathematics Study (1); and the Second International Science Study (2). Other international studies include the first International Assessment of Educational Progress, published as *A World of Differences* (3), and a research paper entitled "Mathematics Achievement of Chinese, Japanese and American Children" (4).

National studies from Canada and the United States are reviewed as follows: the Science Council of Canada's 1984 report, *Science for Every Student: Educating Canadians for Tomorrow's World* (5); the Canadian component of the Second International Science Study (2); the (US) National Assessment of Educational Progress (NAEP) 1986 mathematics study (6); the first (1986) NAEP National Assessment of Computer Competence (7); the 1986 NAEP Science Assessment (8); the (US) Research Triangle Institute's *1985-86 National Survey of Science and Mathematics Education* (9); the American Institute of Physics 1986-87 survey of secondary school physics teachers (10); and the 1988 report of the Office of Technology Assessment (of the U.S. Congress) entitled *Educating Scientists and Engineers: Grade School to Grad School* (11).

Six Provincial studies are also covered in the report. They are: the *British Columbia 1986 Science Assessment* (12); the *Alberta Diploma Examinations Program* and Triennial Assessment (13); a specially commissioned report, *Science for Saskatchewan Schools* (14); the *Manitoba 1986 Science Assessment* (15); and the *Ontario Science Education Report Card*, an analysis of the Ontario results of the Second International Science Study (16); and the corresponding study based on the Québec results, *L'enseignement des sciences dans les écoles secondaires du Québec* (17).

The themes covered in these several studies and the observations made can logically be grouped under three headings: students, teachers and curriculum; that is to say, those who are learning, those who are teaching them, and what they are studying. A further subdivision can be made between mathematics and

science, although there are many similarities in the results of these two subjects. Within each area, therefore, mathematics is considered first, followed by science.

• Student Achievement

A major focus of almost all the research with which we are concerned is student achievement. Overall, it appears that North American students do less well in science and in mathematics than their contemporaries in Europe and Asia, though Canadian youngsters do perform somewhat better than their U.S. neighbours.

Mathematics

Among 13 year-olds from twenty nations and groups surveyed in mathematics (1), Japanese students scored best and Canadians performed somewhere in the middle. The same study showed that by age 18, Canadians were below the average of performers of fifteen countries. It should be remembered, however, that a higher proportion of all 18 year-old Canadian students are enrolled in mathematics courses, a fact that adversely affects the *average* score in such international comparisons of students who can choose whether or not to take a particular subject.

Another international study (3) comparing 13 year-olds in Ireland, Korea, Spain, the U.K., the U.S., and four Canadian provinces, revealed similar patterns. The Korean youngsters performed best in intermediate and complex problem solving in mathematics, whilst the Canadians, depending on their province and language group, were somewhat above or somewhat below the mean.

Yet another study (4) compared Chinese, Japanese and American mathematics students and found that the Asian children were already performing better than the American children *in kindergarten*. The gap then widened from that point on.

For those who are concerned with how North American students are performing in mathematics in comparison with their contemporaries in other countries, these are telling results. One American study (6) drew the following analysis from the overall low achievement levels of North American students in mathematics. Japanese high school graduates were equal in mathematics performance to U.S. college graduates. U.S. business is forced to spend vast sums of money each year providing workers and potential workers with literacy

training, basic skill training and remedial training. Population trends mean that in the very near future there will be more and more people entering the work force from subpopulations which usually perform even more poorly in mathematics.

Though the situation is not so acute in Canada, these are timely issues. Some results are available from within Canada, but of necessity these allow no comparison with the wider population. It should be mentioned that in Alberta (13), an assessment program covering students in grades 3, 6 and 9 showed that almost 90% of the children tested were performing at or above the provincial standard, and 24% were judged outstanding or even higher.

Science

Patterns in science achievement are very similar to those in mathematics. North American students are at or below the average of different nationalities surveyed, whereas Japanese, Korean, Hong Kong and Singapore students regularly perform best. Canadians are considerably better than U.S. students, however.

One international study (3) showed that at age 10, Canadian children rate sixth out of fifteen nations in science performance. Their position is fourth out of seventeen at age 14, but by ages 17 and 18, the Canadian students were eleventh or twelfth out of thirteen. As in mathematics, these results are not quite so dismal as they appear, given that far more Canadian students remain in school to ages 17 and 18, whereas in the highest scoring populations, secondary schools aim to educate an elite of students only. This means that the Canadian results reflect a far wider ability range in students than do the results from Asia. Canadian schools are thus doing a more effective job (than those of other nations) at providing a basic science education to a moderately large proportion of the population but a less effective one at providing a top quality science education to a few. This situation raises important policy questions for Canadians who are concerned to achieve both excellence and equality of opportunity.

Another comparison (3), this time between 13 year-olds from several Canadian provinces, Ireland, Spain, Korea, the U.K. and the U.S., shows most Canadian students of science performing at or just below the international mean. It is no surprise that the best students in this survey were the Koreans, but this time they were closely followed by B.C. students.

An American study of U.S. youngsters' science achievement (8), found that their proficiency was (in the words of the report) "distressingly low". Scrutiny of results from 1969 to the present shows that between 1969 and 1982, there was a decline in U.S. students' science proficiency. Since 1982 there has been an upswing, but over 50% of U.S. 17 year-olds are not ready for jobs involving science of any kind and only 7% of this same age group are adequately prepared for entry to college-level science programs. Sub-groups, namely Blacks and Hispanics, are up to 4 years behind the average in science achievement in the U.S.

Canadian results (12,15,16,17) are as in mathematics -- not as poor as those in the U.S., but not particularly good. Manitoba grade 3 students could not handle measurement in science activities, their grade 6 schoolmates were not good at scientific processes or higher-level skills. Both groups had difficulty with written answers. Achievement of grade 9 students in Manitoba was poor, specifically in observation, hypothesizing, and identification of cause and effect. Ontario youngsters performed around the national average in science. Québec students' performance was above the average at Grade 6, about average in grade 9, and at the bottom in Grade 11.

The best Canadian province overall in terms of student achievement in science is British Columbia. One of the more interesting findings in B.C. is that student performance is actually improving over time. However, society's expectations for science achievement must be increasing at a faster rate, because there is a popular misconception that student performance is declining.

In summary, then, it can be stated that in both mathematics and science, Canadian students do not usually perform as well as the best, but that they are not the worst, and usually rate somewhere near the mean.

• Mathematics, Science, and Gender

There are two other focuses of studies to do with mathematics and science students. One of these is gender difference and the other is the whole area of student attitudes. There are fewer research findings dealing with these issues than with general performance, but the findings do show fairly clear trends.

U.S. studies in mathematics education (3,6,7) demonstrate less difference between males and females than might be expected in mathematics performance. One finding is that while females tend to have more basic knowledge in mathematics, males do better in higher-level applications. Males also show

slightly more competence than females with computers, an area where home influence seems to be extremely important as a predictor of performance.

The overall tendancy as far as gender difference in science education is concerned is that young boys and girls perform equally well in science, but that a gender gap emerges when they are about 12 or 13 and becomes increasingly wider (2,3,8,16). This gap is found in achievement, attitude and career expectations. The biggest difference in attitude and performance is in the area of physics with students in the senior years of high school. Girls tend to dislike physics and choose to study it less, though they are quite positive in their attitude to biology. Some of the explanations posited are that teachers have higher expectations of male students in science classes and also that textbooks contain clear gender bias, with almost exclusively male role models shown in science laboratories and technological fields.

- **Attitudes toward Mathematics and Science**

Some comparative research has been done on student attitudes toward math and science (3,4,6). The results are not surprising, in light of the patterns of achievement which can be seen. Asian students of mathematics obviously take the subject more seriously and are encouraged by their families. For example, 90% of Japanese and Chinese students have desks of their own at home and between 30% and 50% of families purchase extra workbooks to enhance the school program. In the U.S., 63% of students have their own desks and only 1% purchase mathematics workbooks.

Asian students have positive attitudes to homework, whereas North American youngsters are generally negative about homework and do less of it. This was also noted in the case of Québec (17). In the U.S., student attitudes to mathematics deteriorates as the student progresses through school; mathematics at the higher levels is considered to be irrelevant to the world of work and a low proportion of U.S. high school students take mathematics courses at these higher levels.

The most outstanding research finding in the area of attitude to mathematics is that only 23% of Korean 13 year-olds, who are among the *best* performers in mathematics internationally, consider *themselves* good at mathematics. On top of this, most Asian mothers are not satisfied with their children's achievement levels in mathematics. In sharp contrast, American 13 year-olds, who are amongst the weakest in mathematics achievement internationally, mostly (66%) consider that they are good at mathematics and

their mothers are satisfied with their performance. Such complacency is astonishingly ill-founded.

Research and survey findings related to attitudes to science education are not so startling. One international study (2) indicates that most children start with a fairly positive attitude to science. One Canadian study (16) shows that this declines, however, at about the grade 9 level, and that, at the senior high school level, physics is the least popular course, with biology being the one of the most popular.

More than one study points out that children are fairly positive about science itself and about school, but that they feel negatively toward school *science* courses. More Canadian students take science courses than do their American counterparts, but their interest in higher science courses and careers in science is low.

The conclusions about attitudes to school science are fairly consistent, but there has not been a lot of work in this area. Some highly pertinent questions remain to be asked, such as why students seem to dislike school science so much, particularly physics, and why the drop-out rate from science courses is so high. Most of the findings so far reported make statements about the situation, but do not investigate the causes which underly it.

• Teachers of Mathematics and Science

When we turn to research and survey findings about teachers of mathematics and science, we again find that there is not much in-depth information. One Canadian report (16) and two American assessments (8,10) show that North American teachers of science are now better prepared than in the past, though physics teachers are still not in good supply. Most high school science teachers have a science specialization, but many elementary teachers have no science at all in their background, though nearly all are called on to integrate science into their program. More information about these teachers emerges from studies of curriculum and classroom activities.

• Mathematics and Science Classroom Activity

The findings about what goes on in mathematics and science classes can be divided into two parts: the time devoted to these two areas of the whole curriculum and the sorts of activity which take place during the alloted time.

As far as time is concerned, it is clearly established that the time spent on a given subject is a major predictor of student achievement. It is therefore not surprising to learn that Chinese and Japanese students spend far more time in school studying mathematics and science than do North American children (4), and that they also do much more homework in these subjects than do other youngsters.

A major American study (8) established that two thirds of U.S. teachers of grade 3 classes spend less time on science than on establishing discipline, and that 11% of this same group undertake no science teaching whatever. One third of all elementary students in the U.S. do no science homework and in 1986 only half of grade 7 and grade 11 students received more than 3 hours instruction in science per week. Though 94% of U.S. seventh graders took science in 1986, the percentage falls to 58% by grade 11 and few students take advanced science courses in chemistry or physics. Thus, the amount of time devoted to these subjects, particularly science, is considerably less in North America than in the countries where student achievement is highest.

Findings about classroom activity refer mostly to North America, where it seems that very traditional teaching styles prevail. One international study (3) and one U.S. survey (6) indicate that mathematics classes usually consist of teacher lectures, silent deskwork and textbook exercices. There is relatively little use of computers or calculators; group work, projects or innovative activities are not common. In the area of science, the same international study points out that there is not enough hands-on activity in most classes. Another American study reveals that in the U.S., there has been [illegible] following course content or methods and that there is much [illegible]ment in the sort of things that go on in science classes.

• Summary

The overall picture emerging from these studies is of a situation in which North American students of science and mathematics do less well in tests than Japanese, Chinese, Koreans and many Europeans. They do not on the whole have

a positive attitude to mathematics or science and do not choose to do many advanced courses in either field. They spend less time in school on these subjects than do students of other nations, though their teachers are not significantly weaker in subject mastery or in professional qualifications. And classroom activities in both subject areas appear to be dull and old fashioned. It is clear that the whole field of mathematics and science education in North America is in desperate need of renewal. The second part of this paper reviews some of the ways in which this renewal process has already begun.

B Initiatives Being Undertaken for the Renewal of Mathematics and Science Education

The second half of this paper brings together in a systematic fashion many of the recent innovations and intiatives undertaken in North America and in other parts of the world to effect the renewal of mathematics and science education. As before, detailed references are to be found in the bibliography, since the emphasis in this text is on readability and content.

It might reasonably be assumed that the observations noted in so many research reports and surveys over the last ten years would have led to vigorous efforts to remedy the apparently poor state of mathematics and science education in North America. In fact, moves were under way long before this, and as early as the mid 1950s concerned authorities in the U.S. were beginning to look at ways of improving science and mathematics in the schools.

Over the last twenty years massive amounts of money have been spent in that country in an attempt to raise school science and mathematics to world levels and to keep pace with new trends not only in the fields of science and mathematics, but also with developments in how they are taught, and indeed with what aspects of these disciplines need to be emphasized in the classroom.

In Canada there has not been a comparable *national* effort. Much has been done on the provincial level, of course, and [illegible] increase in interest at the national level; however [illegible] expenditures. The major study conducted [illegible] between 1980 and 1984 (5) did lead to much [illegible] years the federal government has launched [illegible] scholarship scheme to promote the study of science at the post-secondary level.

• Indicators of Mathematics and Science Education

In the U.S. much is being done to systematize and rationalize the vast quantities of data available and being collected about science and mathematics education. The National Research Council of the National Academy of Sciences (18) has proposed that information be gathered in several aspects of mathematics and science education: student learning; adults' scientific and mathematical literacy; course enrolments and time allotments for mathematics and science in junior and senior high schools; activities in science and mathematics classrooms; teachers' knowledge and training in these subjects; teacher salaries; curriculum

content, materials, resources. The Council has suggested a four-year testing cycle and an analysis framework taking into account place, race, gender and similar factors.

In a similiar vein, the Council of Chief State School Officers, already mentioned, is running an Indicators Project (19), to develop a system for comparing science and mathematics statistics and other data. The information gathered or planned for includes achievement, enrolment statistics, teacher assignments by subject and by certification status, teacher supply, demand and recruitment. Indeed, many of the States of the U.S. are already testing students regularly in the areas of mathematics and science. The U.S. Council of Chief State School Officers and the Education Commission of the States report that over 40 of the States have ongoing programs of student achievement testing in these subjects. The outcome of these data gathering activities should be the putting together of a sound information base for all future developments in mathematics and science education.

Canadian efforts at the development of indicators of education generally (as distinct from science education) are still in their infancy and developing under the aegis of the Council of Ministers of Education (Canada). Despite their obvious importance to the scientific enterprise in Canada, scientific indicators in this country have traditionally excluded any statistics concerned with science education at the elementary and secondary school level. For example, there is evidence that the numbers of students choosing to take physics in high school are the most significant limiting factor in the number of students entering university science and engineering programs. Yet to date, no national or provincial agencies have shown any interest in examining such data.

• Objectives of Science and Mathematics Education

Thus far, the activities undertaken have been in one sense passive, that is to say that they do not constitute concrete steps, but reporting mechanisms and programs. But on the level of action, the formulation of new objectives and goals is one major sign of change. In the United States, the American Association for the Advancement of Science's Office of Science and Technology Education has undertaken a vast project for the reformulation of the global objectives of science education. Project 2061 (20) is an attempt to foretell the state of science and technology in the year 2061 -- chosen because it is the year that Halley Comet next returns close to the Earth -- and to formulate appropriate educational objectives to prepare us for that point. The intent is for the resulting body of

goals and aims to set the course for science education into the middle of the twenty-first century.

Another ongoing project that aims to assist the renewal of science education is also sponsored by the Office of Science and Technology Education of the American Association for the Advancement of Science. This is the regularly held National Forum on School Science. It brings together theorists and practitioners for the pooling and comparing of ideas and experiences and is obviously a significant recurring event.

In Canada, a significant provincial attempt at putting together an overall blueprint for the renewal of science education has been made in Saskatchewan, where Saskatchewan Education's integrated policy is based on the concept of scientific literacy and the understanding, skills, processes, values and attitudes that this entails (21).

• Curriculum Policy Changes

In practice, it is graduation and college entrance requirements that have profound impact on the reality of science and mathematics education. The trend here is quite clear, both in the U.S. and in Canada. According to the Education Commission of the States (22), there is a definite move to increase the number of compulsory science and mathematics courses for high school graduation. In addition, the level of these courses is being upgraded and a number of advanced diplomas are being introduced. This sort of tightening up is occurring in Canada, also, as part of the reaction to the rather loose graduation structure brought in during the late 60s and the 70s. The undoubted effect will be to expose more students to the study of science and mathematics, hopefully leading to a greater level of interest.

Closely associated with the increase in compulsory courses is the movement for curriculum renewal that is taking place throughout North America. With just a few exceptions, U.S. states and Canadian provinces are undertaken or have already completed major overhauls of curriculum guidelines and the specific content of courses. The Education Commission of the States gathers data about state curriculum guidelines. In their findings, they note a trend to encourage higher order thinking skills in the context of science and mathematics education, and of course the increase in the number of science and mathematics courses required for graduation. They have discovered that the main concerns of state officials in this field are the improvement of science course content,

especially in specific areas such as physics and basic level science, as well as the supply of qualified and competent science teachers.

In Québec, the Minister of Education sought a special advisory report from the Conseil supérieur de l'éducation. The Conseil, in response, stated that in its judgement, the basic framework for science and mathematics education in Québec was sound but that its implementation left much be desired (24). However, the Conseil proposed adjustments to the existing situation concerning, in particular, better balance and consolidation within the sequence of pre-collegial obligatory mathematics courses; better harmonisation between the secondary and collegial levels, and in particular a "vigourous pruning" of the list of pre-collegial prerequisites in mathematics and natural science; and a diversification of pedagogical approaches and practices.

In Canada, the B.C. government's Royal Commission on Education dealt specifically with science education and led to the establishment of a core science curriculum to cover every grade from Kindergarten to Grade 12, which is the graduation year in B.C. Among new science courses which have been developed is that province's Science and Technology 11 course, which has a strong science, technology and society theme in line with the most current trend in science education.

In Alberta, a revision of science programs in schools has also brought about the incorporation of the science, technology and society bias into the curriculum. And another innovation which can be seen elsewhere too is the development of science courses specifically designed for students who do not intend to go into science at the post-secondary level.

In Ontario, a special $3 million initiative aimed at the renewal of primary and junior level science was recently undertaken. This included the development of new policy and curriculum guidelines as well as initiatives concerned with science equipment and inservice teacher education designed to bring the renewal into being (24).

The curriculum changes taking place across the U.S. and Canada are most significant. They are leading to a much more systematic treatment of mathematics and science in schools and are changing the nature of much of what is taught in the classroom. The intent is to make science more relevant to students of all abilities and to link it to the realities of their life. Much is being done to move away from school science as a mere preparation for university science in favour of something which is valuable and relevant for every child and early teenager.

- **School-Based Renewal Initiatives**

A logical extension of the more concentrated science curriculum is the school where science and mathematics are the major thrust of the whole program. The Education Commission of the States (22) reports that specialized or 'magnet' schools for mathematics and or science exist already or are being set up in nearly twenty states in the U.S., some with the support of private organizations and some involving residence away from home. Entrance to such schools is often by competitive selection and the programs offered are advanced and enriched. Summer programs offer similar opportunities on a shorter term, but can reach a far wider population and do not oblige students to live away from home for long periods.

There are a few similar schools and programs in Canada. In the Québec City area, the Découvreurs School Commission has recently inaugurated Québec's first public elementary school where emphasis is placed on science teaching, l'école Fernand-Seguin. In the Toronto area, the Marc-Garneau High School has a strong mathematics, science and technology emphasis, and in many cities there are high schools with advanced academic programs including these subjects. The possibility of science oriented specialized high schools has not been explored to any depth in this country, however. In fact, when the Science Council of Canada (5) proposed the idea in 1984, it was generally not well received.

- **Textbooks and Learning Materials**

The development of curriculum materials has been the focus of much of the renewal activity in science and mathematics education. Publishers are producing attractive materials, mostly of the printed variety, to reflect current trends in science and technology and new developments in teaching techniques. Since, as we have already seen, the use of textbooks is a major part of classroom activity, these materials will continue to have an important impact on science and mathematics education. There is a great need for other material, however, which is only being met to a limited degree. Visual material, that is to say films and videos, as well as resource and enrichment documents, kits and activity units have to be developed to make science classes come alive.

The Canadian Federal Government has a program entitled Science Culture Canada and a Campaign for the Public Awareness of Science and Technology, which have funded the production of some relevant, up-to-date enrichment materials. An example is the recently published booklets on

Technology and Innovation in Canadian Industry (25). These booklets, in French and English, describe several specific Canadian initiatives in areas such as aquaculture and solar-powered flight and suggest ways in which discussion of such innovations could be incorporated into science and social studies courses. They have been accepted by all Ministries of Education except Québec for use in high schools.

The Ontario Ministry of Education has done some valuable work in this respect, as part of the renewal of primary and junior science. It is promoting the production of science kits and has a Learning Materials Development Plan. Money is also being made available for the development of video material by TVO, the province's educational television network, as well as for science education software. In the area of teaching materials, resources, audio-visual aids, software and courseware, then, something is being done, but it is only a beginning and opportunities far outweigh present achievements.

• Renewing the Teachers

This brings us to the question of initiatives focussing on teachers of mathematics and science. The problems of ensuring an adequate supply of science and mathematics teachers who are at the same time well versed in their subject areas and well equipped to teach at the level of their students are common to most countries and are being addressed in many different ways.

The Education Commission for the States (22) reports many novel ways being tried in various parts of the U.S. Many states are offering premium salaries to science and mathematics teachers and are providing loans and/or scholarships for teachers to upgrade either their knowledge or their teaching skills in these subjects. One state goes so far as to use proceeds from the state lottery to finance this retraining. Twenty-five states provide loans for the pre-service training of mathematics and science teachers and at least one is using television for advanced instruction to enable teachers in remote locations to upgrade. As well as these reinforcements of traditional supply methods, some states are turning to alternative certification, that is giving future teachers credit for non-traditional training and experience, while many others are recruiting off-shore, even from West Germany. In-service initiatives in the U.S. include programs to give science teachers in New York experience of science in the workplace, and a system of teacher mentors to enable excellent teachers to give others the benefit of their skills and experience. The overall trends in these U.S. programs aimed at the teachers of science and mathematics are two: to provide subject content courses for those teachers who are not comfortable with

their own mastery of the discipline, and to train teachers in the methodology best suited to the subject they teach and to the students they work with.

Teacher oriented courses in Canada follow similar lines. Ontario has a task force to advise on the pre-service and in-service training of elementary science teachers, and has set up a program of Additional Qualifications courses for these educators. Local school boards and teachers' federations are being urged to make the upgrading and professional development of science and mathematics teachers a high priority. In New Brunswick, teleconferencing is being used in a project to help elementary school science teachers and also to provide advanced content for secondary school teachers. Typical of many provinces are New Brunswick's weekend and summer courses for science teachers.

- **Private Sector Influences**

In the efforts to renew science and mathematics education, there is a whole range of coalitions or strategic alliances that have as their object the bringing together of organisations outside education, such as industry, commerce, government, researchers and so on, and those within the field. Most of these groups operate specific practical programs, rather than sponsor further discussion.

For example, in the U.S., the Triangle Coalition is a national-level alliance of scientists, industrialists and educators who wish to ensure the improvement of science and mathematics education. Its task forces make recommendations concerning problem areas such as educational technology, and at the local level it provides networks, teacher assistance and school-industry alliances.

In Canada, most of the activity has been at the provincial level. In British Columbia, the Association for the Advancement of Science Education runs a network for elementary school science and produces a newsletter. In that same province, the Ministry of Advanced Education, Science and Technology has a "Scientist in the Schools" program, to bring people from industry, laboratories and universities into the classroom. The British Columbia Science Council also has a task force working on ways to support science education in schools. This is one part of the country where a considerable amount of leadership is being shown.

Elsewhere in Canada, there is some private sector involvement in science education. Northern Telecom has instituted a program of awards for students and the SEEDS foundation uses energy sector donations to produce excellent

classroom materials and to run a most successful program of science teacher upgrading. Apart from these initiatives, the Canadian private sector is doing little to advance the cause of science and mathematics education. The Canadian Advanced Technology Association and the Canadian Chamber of Commerce have shown interest, but as yet there is little action.

• Student Oriented Programs

Both in the U.S. and in Canada there are many programs providing recognition for outstanding students in these subjects and encouraging and enabling them to pursue their studies. According to the findings of the Education Commission of the States (22), there are science contest, quizzes and examinations with special prizes. Science fairs and science olympics provide challenge in stepping outside the school program and in encouraging personal projects or the application of classroom-learned skills in new contexts. Business and industry make awards to outstanding students and there are programs to enable young people to attend workshops, camps, work-experience courses and so on.

In Canada, the Canada Scholarship Program is intended to provide moneys for students entering science programs at the university level. This program is not yet in full operation because of jurisdictional problems, among other difficulties.

In the United States there are also some programs targetting minority groups in science and mathematics education. Again, the Education Commission for the States notes such events as science olympiads for native Americans, workshops in mathematics and or science specifically designed for women, and summer programs for the handicapped and minority groups which are not traditionally well represented in the mathematics and science communities.

Conclusion

The United States and Canada provide a study in contrasts when it comes to reaching a national goal such as the renewal of mathematics and science education. On the one hand, the Americans appear worse off than Canadians: their students perform much less well on achievement tests; their teachers are often less qualified; and the social problems that beset their schools, especially in urban areas, are more serious. Yet, on the other, the national will and commitment to change their situation is much superior to the somewhat complacent and disinterested attitudes found, at least at official levels, in Canada.

In the United States, the amounts currently being spent on programs to support the renewal of mathematics and science education at the federal level alone are over $260 million, half of which is distributed to school districts through the States. The other half is allocated to the National Science Foundation for the support of pre-college science and mathematics education programs. Private industry is making major contributions to science and technology education, both directly (such as the IBM's program of giving computers in support of teacher education projects) and indirectly through the establishment of over 80 local alliances to support improved science and mathematics education (such as the Colorado Alliance for Science).

By contrast, in Canada, despite the statements of the Prime Minister at the National Conference on Technology and Innovation in January 1988 about the importance of science and mathematics education in schools, the federal government's targetted expenditures on pre-college science and mathematics education is precisely $0. Some money trickles into the system through the small Science Culture Canada program and indirectly through grants for research into science and mathematics education from SSHRCC.

The private sector's record is no better. Despite frequent criticisms of the state of science and mathematics education in schools, the Canadian private sector's record of support is dismal by comparison with that of the United States. There are of course notable exceptions, such as Shell Canada, Northern Telecom, Apple Canada, and a few others. But, given an opportunity to make a significant move to build a Canadian Alliance in support of science and mathematics education, the Canadian Advanced Technology Association deliberated for a year or more and decided that "there was not much interest" on the part of its members across the country.

On the provincial level, there is a natural tension between the educational authorities, who tend to regard science and mathematics as "merely two subjects of the curriculum" and the scienteific community whose leverage on the provincial school system is very limited. This results, at best, in a standoff in which little gets done, or, at worst, in direct and open hostility such as recently occurred in Alberta where the University of Alberta science faculty and the Minister of Education openly challenged each other in the news media over the quality of science education programs in the province.

The Canadian consensus appears to be limited to acknowledging that science and mathematics education are in need of renewal but that the problem is not sufficiently serious to warrant upsetting the delicate jurisdictional balances between federal and provincial, scientific and educational, or public and private sector. This leaves those who would make change to attempt these on their own and at the local level. There are many projects being undertaken by individual schools and teachers that are underfunded and rarely reported. Their impacts are thus confined to their immediate locations and the lessons learned rarely get shared among the profession.

The foregoing discussion and analysis raises a number of questions for further discussion. Principally, the following should be the focus of immediate debate within every jurisdiction in Canada.

1. To what extent can an educational system that is oriented toward scientific literacy for all also develop scientific and technological excellence? How can this be done?

2. What are the indicators of quality in mathematics and science education? How should these be measured on a regular basis?

3. How can support for the renewal of science and mathematics education be increased? From what sources should this support come? How urgently is it needed?

4. How can we be sure that the present undergraduate teaching of mathematics and science is not contributing to the next generation of problems for school mathematics and science.

5. What incentives are there for students to achieve excellence in mathematics and science? Are these achivements valued in society?

Bibliography

1. Curtis McKnight et al., *The Underachieving Curriculum: Assessing U.S. Mathematics from an International Perspective*. (Champaign, Ill.: Stipes Publishing Company, 1987).

2. International Evaluation Association, *Science Achievement in Seventeen Countries: A Preliminary Report* (Oxford: Pergamon, 1988).

3. Archie Lapointe et al., *A World of Differences: An International Assessment of Mathematics and Science* (Princeton, NJ: Educational Testing Service, 1989).

4. Harold W. Stevenson, Shin-Ying Lee, and James W. Stigler, "Mathematics achievement of Chinese, Japanese and American children," *Science, 231* (14 February 1986) pp. 693-699.

5. Science Council of Canada, *Science for Every Student: Educating Canadians for Tomorrow's World*, Report 36 (Ottawa: Supply and Services Canada, 1984); also, G.W.F. Orpwood and J.-P. Souque et al., *Science Education in Canadian Schools*, Science Council of Canada Background Study 52 (3 volumes) (Ottawa: Supply and Services Canada, 1984).

6. National Assessment of Educational Progress, *The Mathematics Report Card: Are We Measuring Up?* (Princeton, NJ: Educational Testing Service, 1988).

7. National Assessment of Educational Progress, *Computer Competence: The First National Assessment* (Princeton, NJ: Educational Testing Service, April 1988).

8. National Assessment of Educational Progress, *The Science Report Card: Elements of Risk and Recovery* (Princeton, NJ: Educational Testing Service, 1988).

9. Iris Weiss, *Report of the 1985-86 National Survey of Science and Mathematics Education*, Research Triangle Institute, 1987.

10. Michael Neuschatz and Maude Covalt, *Physics in the High Schools*, Findings from the 1986-87 nationwide survey of secondary school teachers of physics (New York: American Institute of Physics, 1988).

11. U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School*, OTA-SET-377 (Washington, D.C.: Government Printing Office, 1988).

12. *British Columbia Science Assessment, 1986, Summary Report* (Victoria: Ministry of Education, 1986).

13. *Alberta Diploma Examinations Program: Provincial Report, June 1988* Administration (Edmonton: Alberta Education, 1988).

14. Paul Hart, *Science for Saskatchewan Schools: Field Study Report and Science for Saskatchewan Schools: A Review of Research Literature, Analysis and Recommendations* (Regina: Saskatchewan Instructional Development and Research Unit, 1987).

15. *Manitoba Science Assessment, 1986, Final Report and Summary Report* (Winnipeg: Manitoba Education, 1986).

16. F. Michael Connelly, *Ontario Science Education Report Card: Canadian National Comparisons* (Toronto: Ontario Ministry of Education 1987).

17. Gilles Dussault, *L'enseignement des sciences dans les écoles secondaires du Québec: Bilan, recommandations et interrogations* (Hull: Université du Québec à Hull, 1988). It must be noted that the Dussault report has been criticized, and justly so, for its treatment of students of 5th year secondary school. Students at the end of secondary school in Québec have received 5 years of schooling whereas students of other countries have generally received 6 years. Further, students at this level have not chosen to specialize whereas this is not always the case in other countries. These two factors render some comparisons problematic.

18. Committee on Indicators of Precollege Science and Mathematics Education, *Indicators of Precollege Education in Science and Mathematics: A Preliminary Review (1985)* and *Improving Indicators of the Quality of Science and Mathematics Education in Grades K-12* (1988) (Washington: National Research Council of the Academy of Sciences).

19. Three project reports are available at this time: 1) *State Education Indicators on Science & Math, Results of a 50-State Inventory*; 2) *State Policies Related to Science & Mathematics Education*; and 3) *Indicators of Science & Mathematics Education: Providing Tools for State Policymakers*. Each report can be obtained for $2.00 per copy, pre-paid, from Rolf Blank, Director, Science/Math Indicators Project, Council of Chief State School Officers, 400 N. Capitol Street, N.W., Washington, D.C. 20001.

20. American Association for the Advancement of Science, *Science for All Americans*, Report of phase 1 of Project 2061 (Washington D.C.: A.A.A.S., 1989).

21. See for example, Saskatchewan Education, *Science Education Curriculum Development Newsletter*, Regina, January 1988.

22. Education Commission of the States, *State Initiatives to Improve Science and Mathematics Education* (Denver, Co.: E.C.S., 1987).

23. Conseil supérieur de l'éducation du Québec, *Les sciences de la nature et la mathématique au deuxième cycle du secondaire* (Québec, CSÉ, January 1989). In a just recently published Advisory statement required in virtue of the advisory council's mandate, recent proposed ministerial projects have come under more serious criticism. "Serious reserve" is expressed concerning a number of the proposals. Further, the Conseil suggests that the nature of the issues at stake might well lead the Minister to completely revise the pedagogical regime. See *Améliorer l'éducation scientifique sans compromettre l'orientation des élèves. Les sciences de la nature et la mathématique au deuxième cycle du secondaire*, Avis au ministre de l'Éducation et ministre de l'Enseignement supérieur et de la Science, Québec, November 1989).

24. Ontario, *Science in Primary and Junior Education* (Toronto: Ontario Ministry of Education, 1986).

25. Graham Orpwood, Douglas Wrigglesworth, and Tim Fielding *Technology and Innovation in Canadian Industry* (Ottawa: Ministry of State, Science and Technology and Orpwood Associates, 1989).

Annexe

Science and Mathematics Education in North America:

ADVANCE OR DECLINE ?

- REPORT -

by

Graham Orpwood

Conseil de la science et de la technologie

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Introduction

This report is the final report prepared according to a contract between Orpwood Associates and the Conseil de la science et de la technologie for a study in the field of science and mathematics education at the primary and secondary levels.

The study's terms of reference[1] recognize, as the "problématique" of the study, that science and mathematics education at the primary and secondary levels are the objects of much concern, assessment, and renewal in North America today. And in order to set the discussion of these issues in Québec in a broader North American context, the study has been focused on two principal objectives:

1. To review the most significant studies of science and mathematics education at the primary and secondary levels which have been undertaken in the past few years and to identify their principal findings;

2. To describe some of the initiatives undertaken in North America whose purposes have been to improve the state of science and mathematics education at the elementary and secondary levels.

The terms of reference suggest a series of more specific questions to be addressed in regard to each of the studies and initiatives. The present report provides a review of these studies and initiatives, with an analysis of their principal themes.

The study is divided into two parts according the two objectives noted above. Part A describes a variety of studies concerning the state of science and mathematics education in the United States and Canada and the Part B outlines a variety of initiatives to improve science and mathematics education in each country.

Some of the major highlights of the studies and initiatives examined in this report are reprinted textually, and to better represent this they are presented in italics and in a distinct font.

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1 The contract itself is in French. In this report its content is paraphrased in English.

Part A Assessments of Science and Mathematics Education

These assessments are further subdivided into four categories:

- International studies;
- National studies (Canada);
- National studies (US);
- Provincial studies (Canada).

■ International Studies

During the past five years there has been an unprecedented number of international studies of science and mathematics education. The most important of these have been sponsored by the International Association for the Evaluation of Educational Achievement (IEA). The Second International Mathematics Study (SIMS) was conducted in the early 1980s and, while this date is somewhat earlier than the majority of the studies reviewed here, the importance of this study warrants its inclusion. In science, the Second International Science study (SISS) took place in the late 1980s and its final results are still awaiting publication in Canada (although the US results and preliminary Canadian results are already available).

Two additional international studies are also noteworthy. The most recent international study to be reviewed is the first International Assessment of Educational Progress, developed from the US National Assessment of Educational Progress, whose study of mathematics and science in five countries and four Canadian provinces has recently been released. And finally, a study reported in *Science* in February 1986 compares mathematics teaching and student achievement of Chinese, Japanese and American children.

1 Second International Mathematics Study

The Second International Mathematics Study (SIMS) was a comprehensive survey of the teaching and learning of mathematics in the schools of some twenty countries (educational systems) around the world.[2] In the study detailed information was obtained on the content of the intended mathematics curriculum, what mathematics was actually taught by the teachers, and how that mathematics was taught. Student achievement and attitudes were assessed using internationally developed tests and questionnaires that were taken by random samples of mathematics classes in each country. The study was targeted at 13 year olds in most countries (12 year olds in Japan and Hong Kong) (population A) and at those students at the end of secondary school who were entoled in advanced college-preparatory mathematics courses (population B).

In Canada, the provinces of British Columbia and Ontario took part in SIMS, along with Belgium, England and Wales, Finland, France, Hong Kong, Hungary, Israel, Japan, Luxembourg, Netherlands, New Zealand, Nigeria, Scotland, Swaziland, Sweden, Thailand and the United States.[3] Some of these countries participated at the lower population level only.

At the 13 year old level (population A), five content areas were tested: arithmetic, algebra, geometry, statistics and measurement. In each of these content areas, the Japanese students were significantly more advanced than students from other countries, both Canadian provinces placed in the middle group overall, though British Columbia was very close to Japan in Arithmetic.

At the 18 year old level, six topics were tested: sets and relations, number systems, algebra, geometry, functions and calculus, and probability and statistics. Canadians did less well at this level, falling into the mid or lower ranges amongst the 15 countries in each of these areas. However, an important but often overlooked factor must be taken into account at this level.

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2 This section is adapted from the Executive Summary of *The Underachieving Curriculum: Assessing U.S. School Mathematics from an International Perspective* by Curtis McKnight et al. (Champaign, Ill.: Stipes Publishing Company, 1987).

3 Ontario results for population A are described in: L. McLean, D. Raphael, and M. Wahlstrom, "The Second International Study of Mathematics: An overview of the Ontario Grade 8 study," *Orbit* 67, pp 4-7; and for population B in: D. Raphael, M. Wahlstrom, and L. McLean "The Second International Study of Mathematics: An overview of the Ontario Grade 12/13 study," *Orbit* 68, pp 7-10.

SIMS also used some more sophisticated indicators to characterise mathematics education. These included "opportunity to learn" – a measure of the extent to which topics on the test were also topics that had been taught to the students – and "program retentivity" – the proportion of a given age group enroled in a course designed for that age group, in this case Grade 12 mathematics. When one considers that the average of a set of test scores depends not only on what the students have learned, but also on what they have been taught, and on the particular selection of students taking the test, these additional indices become important. In this case, for example, the study found that Ontario's 18-year old math students represented 19% of their entire age group, compared with 12% of the Japanese, 8-9% of the American and only 6% of the English students. Use of this factor to adjust the average test scores can generate a better index of the overall effectiveness of school math programs.[4]

The Ontario version of the SIMS test for population B also included a set of items corresponding to the Ontario Mathematics Achievement Test (OMAT) from 1968, which was formerly used as part of the admissions procedure for Ontario universities. The same items were used as part of a research study which took place in 1976. Using some minor adjustments to take into account changes in the curriculum during the intervening years, a longitudinal comparison of mathematics achievement in Ontario was possible. This showed that "a consistent standard of student mathematics achievement from 1968 to 1982 has apparently been maintained" and that "the problem of declining achievement seen in the United States was not apparent . . . in Ontario."[5]

2 Second International Science Study

During the period 1983-86, the IEA sponsored a study of science achievement in twenty countries at three levels in each school system: 10 year olds; 14 year olds; and the final year of secondary school. The preliminary results from seventeen of these countries (including English and French Canada) were published in 1988. The final international results and the Canadian results are still in publication. For Canada, this study was particularly important because it represented the first time that all provinces and both major language groups participated in the same study of student achievement.

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4 Private communication (Howard Russell, OISE) on research in progress with data from *The Underachieving Curriculum: Assessing U.S. School Mathematics from an International Perspective*, 1987.

5 Merlin Wahlstrom, Dennis Raphael, and Les McLean, "Comparative Analysis of Ontario Senior Division Mathematics Achievement, 1968-82," *Canadian Journal of Education* 11:2 (1986), p. 178.

Overall, Canadian students placed 6th out of 15 at the grade 4/5 level, 4th out of 17 at the grade 8/9 level, but 11th or 12th out of 13 in Biology, Chemistry and Physics at the grade 12/13 level.[6] Of particular note were the facts that in senior Biology, 95% of Canadian schools performed lower than the lowest school in the highest scoring country (Singapore) and in Physics, 93% of Canadian schools performed lower than the lowest school in Hong Kong (which was the highest scoring country in that subject).

Again however, the % of the age cohort still in school needs to be taken into account. In the case of English Canada, for instance, 71% of the age group were still in school and therefore formed the target population which was sampled for testing, compared with 20% for Hong Kong, and 17% for Singapore. The average scores must therefore be interpreted in this light. This study shows dramatic differences between those countries such as Canada that have not aimed at educating an elite in secondary school and those that have aimed at educating a smaller proportion of the population to a higher level. These policy choices made (in many cases) over 20 years ago are reflected in the results of this study.

Also measured in this study was the difference between scores of males and females in each country. Here, the gender differences for Canadian students fell in the middle of the range at each of the three population levels. The pattern of variation here is complex however and requires further analysis. As noted earlier, there are many additional analyses that will be available when the final reports of the study are published (in 1989).

Within Canada, SISS was conducted as two nationally coordinated studies (English and French) comprising all provinces and territories. The results of the study within these Canadian jurisdictions are described later (under "national studies").

3 A World of Differences: An International Assessment of Mathematics and Science[7]

This study involved the assessment of science and mathematics achievement amongst 13 year olds in five countries (Ireland, Korea, Spain, United Kingdom and United States) and four Canadian provinces (British Columbia,

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6 IEA, *Science Achievement in Seventeen Countries: A Preliminary Report* (Oxford: Pergamon, 1988), p. 3.

7 Archie Lapointe et al., *A World of Differences: An international assessment of mathematics and science* (Princeton, NJ: Educational Testing Service, 1989).

New Brunswick, Ontario and Québec). In the last three of these provinces, the English and French language groups were identified separately. A random sample of about 2000 students from 100 schools was selected from each population and students were given a 45-minute math test and a 45 minute science test, comprising questions drawn from the (US) National Assessment of Educational Progress. In addition, students answered questions about their school experiences and attitudes and teachers rated students' exposure to the concepts tested.

The following highlights are reprinted from the study's report.[8]

MATHEMATICS

In Korea, 78 percent of the 13-year-olds can use intermediate mathematics skills to solve two-step problems (level 500 on a hypothetical 1,000 point scale) compared to only 40 percent of their counterparts in Ontario (French) and the United States.

Forty percent of Korea's 13-year-old students understand measurement and geometry concepts and are successful at solving even more complex problems (Level 600). Less than 10 percent of those from Ontario (French) and the United States have the same level skills.

Korea's 13-year-olds demonstrate the highest overall mathematics achievement, well above the mean of all participating countries and provinces. The other 11 populations cluster themselves into three lower-performing groups.

Four countries and provinces perform above the mean: Quebec (French), British Columbia, Quebec (English), and New Brunswick (English). Achievement is about at the mean for five populations: Ontario (English), New Brunswick (French), Spain, the United Kingdom, and Ireland. Finally, below the mean are students from Ontario (French) and the United States.

Thirteen-year-old boys and girls perform about at the same level in 10 of the 12 populations assessed. The two exceptions are Korea and Spain, in which boys outperform girls.

Classroom instructional practices are similar in all of the countries and provinces assessed with most 13-year-olds (more than 70%) reporting that they regularly listen to teacher lectures and work mathematics problems on their own. Fewer students (less than one-third) report working in small groups on a regular basis.

Despite their poor overall performance, about two-thirds of the United States' 13-year-olds feel that "they are good at mathematics." Only 23

8 Ibid, pp. 10-11.

percent of their Korean counterparts, the best achievers, share the same attitude.

In about half of the comparisons, students perform better in various mathematics topics than their teachers' opportunity-to-learn ratings would suggest.

SCIENCE

More than 70 percent of the 13-year-olds in British Columbia and Korea can use scientific procedures and analyse scientific data (Level 500 on a hypothetical 1,000 point scale), while only about 35 to 40 percent of their peers in the United States, Ireland, Ontario (French), and New Brunswick (French) demonstrate the same degree of competence.

More than 30 percent of British Columbia's and Korea's students are able to apply more advanced scientific knowledge and principles (level 600), compared to less than 10 percent of their counterparts in Ireland, Ontario (French), and New Brunswick (French).

British Columbia's and Korea's 13-year-olds perform well above the mean on the science assessment; the other ten populations divide themselves into two distinct groups in terms of achievement.

Half the populations perform about at the mean; the United Kingdom, Quebec (English), Ontario (English), Quebec, (French), New Brunswick (English), and Spain. A second group of four, the United States, Ireland, Ontario (French), and New Brunswick (French), perform well below the mean.

Thirteen-year-old boys outperform their female counterparts in science in all 12 populations assessed except the United Kingdom and the United States. The greatest difference was in Korea, where boys outperform girls by nearly 40 scale points.

Students in the United Kingdom report the most involvement with hands-on science experiments and those in New Brunswick (English) and the United States report the least involvement.

In all populations except Spain, students generally perform better in science topics than their teachers' opportunity-to-learn ratings would suggest.

GENERAL

In all countries and provinces assessed, the greater the amount of time spent watching television, the poorer student performance is in both mathematics and science. Survey data do not address cause and effect.

Except in Spain and Ireland, more than 50 percent of the 13-year-olds report spending one hour or less each day doing homework assignments

for all of their school subjects combined. The norm for Spanish and Irish students is two or more hours per day.

4 Mathematics Achievement of Chinese, Japanese and American Children[9]

One of the concerns about international comparative studies of student achievement is that they can be culturally biased. In this study a team of bilingual researchers from each culture constructed tests and other research instruments with the aim of eliminating as much cultural bias as possible. This study also examined achievement at the levels of kindergarten and grades 1 and 5 to test the hypothesis that the American students' lag behind children from such countries as Japan has its origins earlier rather than later in their scholastic careers.

Children in one city in each country were studied: Minneapolis in the United States; Sendai in Japan; and Taipei in Taiwan. Ten schools in each city were selected and, within each of these two classrooms at each grade level, and within each of these, six boys and six girls were chosen at random. This process yielded a sample of 288 children for each city. Not only were the children given a battery of tests; observations were made in classrooms and teachers and mothers were interviewed.

In mathematics achievement, the American children were worse than their oriental counterparts at kindergarten level and the differences became more marked as they got older. The remainder of the observations gave some clues to the reasons for this: the American students in grade 1 spent about 70% of their time on "academic" activities, compared with 80% of the Japanese and 85% of the Chinese students' time. Less than 20% of the American students' time was spent on mathematics, less than either of the other groups.

Homework was another major point of difference. At the fifth grade level for example, US mothers estimated that about 46 minutes per day were spent on homework; by contrast, the Japanese student spends 114 minutes a day at that level. On the weekend the contrast was even greater. And while 63% of American fifth graders had desks at home where they did their homework, over 90% of both Japanese and Chinese students had their own desks. Workbooks in science were purchased by 1% of American parents compared with 29% of Japanese and 51% of Chinese parents. On tests of [illegible]erican children gene-

9 Harold W. Stevenson, Shin-Ying Lee, and James W. Stigler, "[illegible]ent of Chinese, Japanese and American children," *Science*, 231 (14 Febru[illegible]

rally did not like doing homework whereas Japanese and Chinese students had much more positive attitudes.

Interestingly, American mothers expressed reasonable satisfaction with their children's mathematics achievement whereas Japanese and Chinese mothers rated their own children's math achievement lower. 60% of American mothers were "very satisfied" with their child's academic performance. fewer than 10% of Japanese and Chinese mothers expressed themselves as "very satisfied."

This study suggests that important differences in mathematics achievement emerge from the home and increase during the period of elementary schooling. These findings should be a major factor in any policy discussions concerning ways to improve mathematics and science education in Canada.

National Studies (Canada)

Two principal studies of science education have taken place in Canada during the past decade. The Science Council of Canada conducted a major research study of science education in Canadian schools in cooperation with all provincial ministries of education and, in 1984, issued a report, *Science for Every Student: Educating Canadians for Tomorrow's World*.[10] This report was based in part on an extensive program of research into the state of science education in Canadian classrooms.[11] This research was not permitted to assess students' knowledge of science. It did however collect a large body of information about the provisions made for learning science. The study reviewed the intended curriculum (as represented by Ministry of Education policies and programs), the planned curriculum (as represented by the teachers' beliefs and the contents of science textbooks) and the taught curriculum (as revealed by a series of case studies in science classrooms).

The Council was assisted in its interpretation of this research program by a series of "deliberative conferences" held in each province and territory that led to the formation of a series of 8 recommendations for the renewal of science education in Canada:

1. Elementary schools must provide science education for all their students;
2. Girls must be encourages to continue with science throughout their schooling;
3. High achievers and science enthusiasts must receive greater challenge;
4. Science education must provide a more accurate view of the practice, uses and limitations of science;
5. Science education must include study of how science, technology and society interact;
6. Students must be taught how Canadians have contributed to science and how science has affected Canadian society;

10 Science Council of Canada, *Science for Every Student: Educating Canadians for Tomorrow's World*, Report 36 (Ottawa: Supply and Services Canada, 1984).

11 G.W.F. Orpwood and J.-P. Souque et al., *Science Education in Canadian Schools*, Science Council of Canada Background Study 52 (3 volumes), (Ottawa: Supply and Services Canada, 1984).

7. Technology courses must be included in the secondary school curriculum;

8. Teachers and curriculum planners must evaluate students' progress toward all the goals of science education, not just their learning of scientific content.[12]

Since 1984, considerable progress has been made in implementing these proposals and a later section of this report will review some of these.

The second major national study was the Canadian component of the Second International Science Study, described earlier in this report. The Canadian study itself comprised two parts, representing the English and French populations, and the final reports of each are still in press.[13]

One unique feature of the (Anglophone) Canadian study was the inclusion of measures of students' attitudes toward science. The study found that "overall, student attitude toward science seems to improve with increasing grade level." The attitude scale was further subdivided into attitudes to school, to the importance of science, to "school science," and to careers in science. At the grade 5 level, while attitudes toward school and toward science are generally positive, the science taught in school is not perceived as positively. At the grade 9 level, students were generally favourable toward careers in science; yet they were uncertain about the importance of science for having a good job. At the grade 12/13 level (where the population tested was limited to those who had elected to study science), attitudes on all scales were generally very positive.

While regional differences in these attitudes were relatively small but gender differences were large. And the pattern of increased gender differentiation with increasing age was found both in attitudes and in achievement. For example, at grade 5 males averaged 58.3% and females 55%, a spread of 3.3%; at grade 9 males scored 64.0% and females 58.3%, a spread of 5.7%; and at grades 12/13, spreads of 3.1% in physics, 5.7% in biology, and 8% in chemistry were observed. In attitudes, girls liked science more than boys at the grade 5 level; the reverse was true at grade 9 and the two were close at grades 12/13. In discussing career prospects, however, the traditional patterns of more males than females expecting to enter science based careers were noted.

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12 Science Council of Canada, op. cit., pp. 33-45.

13 The following information is taken from an early draft of the report of the English-language study, to be published by OISE Press, Toronto, during 1989.

▪ National Studies (United States)

A series of studies have been conducted in the United States during the past several years, and the following are particularly noteworthy.

1 From the **National Academy of Sciences:** ***Everybody Counts*****, a report from the Mathematical Sciences Education Board and the National Research Council.**

This report has been ordered but not received by the consultant at the time of writing.

2 From the **National Council of Teachers of Mathematics: Report of the Fourth National Assessment of Educational Progress in Mathematics.**

This report has been ordered but not received by the consultant at the time of writing.

3 ***The 1986 National Mathematics Assessment***

OVERVIEW[14]

Why Mathematics Counts

The skills and expertise of a country's workforce are the foundation of its economic success. Lately, in our country, this foundation appears too fragile to withstand the challenges of the 21st century.

- *The most recent international mathematics study reported that average Japanese students exhibited higher levels of achievement than the top 5 percent of American students enroled in college preparatory mathematics courses. As a case in po*

[14] *The Mathematics Report Card: Are We Measuring Up ?*, Trends and Achievement Based on the 1986 National Assessment of Educational Progress (Princeton, NJ: Educational Testing Service, 1988): 8-13.

semiconductor company recently opening a plant in the Southeastern United States had to use college students at the graduate level to perform statistical quality control functions; the same jobs were performed by high-school graduates in Japan.

- One out of three major corporations already provides new workers with basic reading, writing, and arithmetic courses. If current demographic and economic trends continue, American business will hire a million new people a year who can't read, write, or count. Teaching them how, and absorbing the lost productivity while they are learning, will cost industry $25 billion a year for as long as it takes - and nobody seems to know how long that will be.

- American colleges have reported a 10-to 30-percent rise in demand over the past several years for remedial coursework in mathematics for incoming freshmen. As diagnosed in one study,a these young people are not defined as at-risk, yet they are not workforce ready. For the at-risk populations, the mismatch between workplace needs and workforce skills is even greater.

- Looking toward the year 2000, the fastest growing occupations require employees to have much higher math, language, and reasoning capabilities than do current occupations.

Too many students leave high school without the mathematical understanding that will allow them to participate fully as workers and citizens in contemporary society. As these young people enter universities and business, American college faculty and employers must anticipate additional burdens. As long as the supply of adequately prepared pre-collegiate students remains substandard, it will be difficult for these institutions to assume the dual responsibility of remedial and specialized training and without highly trained personnel, the United States risks forfeiting its competitive edge in world and domestic markets.

Even for those working in less scientifically specialized areas, technological innovations require the ability to learn and adapt to new conditions. Studies of technological change have reached differing conclusions as to the nature and extent of its impact on job skill requirements, but it is certain that the current generation of students will need to work with increasingly large and complex bodies of information in performing even basic tasks. From the basic computational skills required to organize and track large-scale shipments of merchandise to the higher-level expertise necessary to make technological discoveries, it is clear that mathematical abilities will be critical to our nation's continued economic success.

Highlights from NAEP's Mathematics Assessment

NAEP's 1986 mathematics assessment provides a timely account of student achievement in this vital subject, and the results highlight the need for even greater commitment to school mathematics programs. Trends across four assessments since 1973 offer a comprehensive view of achievement patterns for students at age 9, 13 and 17.

- *Recent national trends in mathematics performance are somewhat encouraging, particularly for students at age 9 and 17. Subpopulations of students who performed comparatively poorly in past assessments have shown significant improvement in average proficiency since 1978: at all three ages, Black and Hispanic students made appreciable gains, as did students living in the Southeast.*

- *While average performance has improved since 1978, the gains have been confined primarily to lower-order skills. The highest level of performance attained by any substantial proportion of students in 1986 reflects only moderately complex skills and understandings. Most students, even at age 17, do not possess the breadth and depth of mathematics proficiency needed for advanced study in secondary school mathematics.*

While we may be recovering from the doldrums of poor performance that characterized the 1970's, it is crucial that we do even better to reach expected or hoped-for levels of achievement. Improvements are needed, not only in average proficiency, but also in the number of students who reach the upper levels of performance.

Other Findings

- *Discrepancies between the level of mathematics commonly taught in elementary, middle, and high schools and what students know and can do in the subject appear to increase over the school years, especially for Black and Hispanic students. Only about half of all the 17-year-olds in the 1986 assessment reached a level of proficiency associated with material taught in junior high school mathematics.*

- *Mathematics instruction in 1986, as in previous years, continues to be dominated by teachers explanations, chalkboard presentations, and reliance on textbooks and workbooks. More innovative forms of instruction - such as those involving small group activities, laboratory work, and special projects - remain disappointingly rare.*

- *Students reported more homework and testing in mathematics in 1986 than in previous assessments, perhaps indicating a growth in academic expectations in schools.*

- *Students appear to gain basic mathematical knowledge and skills in numbers and operations between grade 3 and 7, while higher-level applications in numbers and operations develop steadily across the three grade levels. Females outperformed males in the area of basic knowledge and skills while males had the advantage in higher-level applications.*

- *Although the role of technology in the mathematics classroom appears to be changing the benefits of using computers and calculators seem to be available primarily to small proportions of students who are in the upper range of ability or in the upper grades.*

- *Although more high school students in 1986 than in previous years reported taking higher-level mathematics courses, including Algebra II, Geometry, and Calculus, the overall percentage of students taking these advanced courses remains disappointingly low.*

- *High school students whose parents encourage mathematics course-taking and have higher levels of education tend to exhibit higher mathematics proficiency than those who lack this home support.*

- *Students who enjoy mathematics and perceive its relevance to everyday life tend to have higher proficiency scores than students with more negative perspectives. At the same time, students' enjoyment of and confidence in mathematics appear to wane as they progress through their schooling. Most perceive that the subject is composed mainly of rule memorisation, and expect to have little use for mathematics skills in their future work lives.*

Summary of Assessment Procedures

This report chronicles trends in proficiency across four mathematics assessments conducted in 1972-73, 1977-78, 1981-82 and 1985-86. (For convenience, each assessment will be referred to by the last half of the school year in which it occurred - 1973, 1978, 1982, and 1986.) Each of the four mathematics assessments involved nationally representative samples of 9-, 13-, and 17-year-olds, and together the assessments generated data from a total of 150,000 students for the examination of trends. In the 1986 assessment, NAEP sampled students by grade as well as age, making available a second data set based on 34,000 additional students in grades 3, 7, and 11.

The mathematics assessments included both open-ended and multiple-choice questions covering a wide range of content and process areas. Student background information gathered during each administration permits consideration of trends in relation to school, home, and attitudinal factors.

The data were analysed using Item Response Theory (IRT) scaling technology and are summarized on a common scale (0 to 500) to facilitate direct comparisons across assessment years for age groups and subpopulations. To provide a basis for interpreting the results, the

report describes what students attaining different proficiency levels on the scale are able to do. Based on the assessment results, five levels of proficiency have been defined.

Level 150 Simple Arithmetic Facts;

Level 200 Beginning Skills and Understanding;

Level 250 Basic Operations and Beginning Problem Solving;

Level 300 Moderately Complex Procedures and Reasoning;

Level 350 Multi-step Problem Solving and Algebra.

NAEP's mathematics scale was computed as a weighted composite of proficiency on five content area subscales - knowledge and skills, higher-level applications, measurement, geometry, and algebra. Thus, for the most recent assessment, results are also available indicating students' relative strengths and weaknesses across these content areas.

Reflections

The assessment findings show both encouraging and discouraging trends for mathematics education in the United States. It is encouraging to see improvements in performance occurring across such a wide segment of the student population, especially among Black and Hispanic students and those in the Southeast. However, this good news must be tempered by continuing concern over the generally low levels of performance exhibited by most high school students and by the fact that the majority of improvement shown resulted from increased performance in low-level skills.

Evidence concerning the nature of mathematics education suggests that the curriculum continues to be dominated by paper-and-pencil drills on basic computation. Little evidence appears of any widespread use of calculators, computers, or mathematics projects. This picture reflects classrooms more concerned with students' rote use of procedures than with their understanding of concepts and development of higher-order thinking skills. The continuance of such a pattern offers little hope that the mathematics education of our children will achieve the goals being set by the recent educational excellence movement.

Findings from the 1986 assessment, however, indicate that recent reforms directed toward increasing requirements in high school mathematics education, and schooling in general, may be beginning to have some effect in raising the overall performance of our students.

Achieving a higher-quality mathematics curriculum across schools in the United States will require new materials, effective instructional methods, and improved means of evaluating student performance. There are many well-qualified and dedicated teachers in our classrooms

capable of promoting improved ways of learning. In order to do so, our teachers will need the support of administrators, parents, and the public at large. No longer can society afford to view mathematics as a subject for a chosen few or as a domain solely composed of arithmetic skills. Students must come to see it as a way of thinking, communicating, and resolving problems. Until American schools move toward these more ambitious goals in mathematics instruction, there is little hope that current levels of achievement will sow any appreciable gain.

4 The First National Assessment of Computer Competence

OVERVIEW[15]

In the 1985-86 school year, the National Assessment of Educational Progress (NAEP) surveyed the nation's third-, seventh-, and eleventh-grade students for their knowledge and skill in using a computer. The result of the assessment is this report, which attempts to capture the interacting forces influencing computer competence among students. It deals with the tremendous differences of opinion about what students should learn about computers and what skills they should be taught. Given these circumstances, this assessment provides a baseline for judging students' performance; it is a first attempt at characterizing the computer competence of the nation's young people by means of a national survey.

Major Findings

Several key findings emerge from this first national assessment of computer competence.

- *Students generally had difficulty answering questions on the assessment especially questions about computer applications and programming;*
- *The experiences of having used a computer, of studying computers in school, and of having access to a computer at home are positively related to computer competence;*
- *Most students like using computers and want greater access to them;*
- *Much learning about computers takes place outside of school and independent of formal instruction. Across demographic subgroups, the increased competence associated with having a computer at home is comparable to the advantage linked to studying and using*

15 National Assessment of Educational Progress, *Computer Competence: The First National Assessment* (Princeton, NJ: Educational Testing Service, April 1988): 5-8.

computers at school. Students who study computers at school and have access to a computer at home are the most competent;

- Computers are seldom used in subject areas such as reading, math, or science. Rather, the use of computers in schools is largely confined to computing classes;

- Males, in general, demonstrate a slightly higher level of computer competence than females;

- There are clear racial/ethnic differences in computer competence, favouring White students over Black and Hispanic students. These differences are present even between students who have comparable levels of experience. But the differences are accentuated by greater experience with computers among White students.

Other subgroup comparisons show an advantage for:

- students whose parents are college graduates;

- students who attend non-public schools;

- students who live in high socioeconomic metropolitan area;

- students who live in the northeastern United States.

These subgroups are most likely to have used a computer, to be studying computers in school, and to have a computer at home.

- Many compute coordinators have minimal training in computer studies and rate themselves as mediocre in their ability to use computers.

The Significance of This Assessment

The significance of this report is two-fold: First, it reveals national baseline information about computer competence; second, it relates competence to instructional and access variables. But the report also describes other important information, such as who use computers, where and how often they are used, and the purposes for which they are used. In addition, the report describes students' attitudes toward computers - whether they like them and perceive them as useful.

The report relates key background variables, such as sex, race/ethnicity, and parental education, to computer access, instruction, and computer competence. This knowledge can alert decision makers to possible inequities in the allocation of instructional resources and might be used to inform policy decisions. Finally, this report describes the characteristics of computer coordinators, their training and the

confidence they have in their own ability to use a computer. The assessment shows where today's young people stand with respect to computer competence and suggests how education in the field can be improved.

The Importance of Computer Competence

America's prominence in the world economy rests to a large extent upon its technological competitiveness. We are no longer so much a nation rich in industry as a nation rich in information. Our future industrial strength depends on how effectively we can use computer-based technologies, such as robotics and computer-aided design.

In the office, microcomputers are now standard equipment, largely displacing typewriters for the tasks of writing letters, memos, and reports. Computers can help manage large amounts of information, such as inventories and distribution lists. Increasingly, computers are used to create high-quality graphics, publish newspapers and magazines, and communicate electronically. Experienced workers find that they must learn computer skills to be competitive in their fields. Secretaries must have word processing skills; commercial artists must be able to use computer-generated graphics; auto parts clerks must be able to search large databases. Across the professional landscape, computers enhance both creativity and efficiency.

In the home, computers are being used more frequently for such purposes as managing personal finances and keeping up with correspondence. Using educational software, children can design experiment, compose music, and graph equations. People of all ages can enjoy the recreational uses of a computer, which vary from computerized chess to flight simulation.

American education has also been deeply affected by the computer revolution. No longer is it sufficient to be competent in the three R's. In A Nation at Risk, the National Commission on Excellence in Education recognised a fourth basic skill: Computer competence. Schools have reacted quickly to the need for computer-literate Americans. In 1980, 15 percent of elementary schools and 50 percent of secondary schools offered instruction in the use of computers. By 1985, 82 percent of elementary schools and 93 percent of secondary schools offered such instruction.

The meteoric rise in the popularity of computers in education has been accompanied by considerable optimism. But it has not been without problems. Teachers with little or no training in computers found themselves teaching introductory courses. Confusion reigned about what to teach. Initially, most instruction in secondary schools was in computer programming, particularly in the programming language BASIC, because it often accompanied computers and required no additional expense.

By 1986, the time was ripe for the first nationwide assessment of computer competence. The assessment was a large-scale project, involving 24,000 students in three grades. To advise NAEP in planning the assessment, a Learning Area Committee on computer Competence was formed. The committee, composed of experts in computer education, was charged with recommending which skills should be assessed and how they should be measured. Although most of the major recommendations were followed, an important one was not. The committee felt that an assessment of computer competence would be most effective if a hands-on or performance component were included. Unfortunately, the high costs of performance testing prohibited using this method. The assessment was therefore limited to the pencil-and paper forma but went beyond multiple-choice items by including some open-ended questions.

NAEP, the Nation's Report Card, hopes that this will be the first in a series of assessments of computer competence. These will enable NAEP to track the progress of American youth in the decades ahead. This first assessment will provide a baseline for understanding computer education in America, how far we have come, and how far we have yet to go.

5 The 1986 National Science Assessment

INTERPRETIVE OVERVIEW[16]

The distinctive character of our own time lies in the vast and constantly increasing part which is played by natural knowledge. Not only is our daily life shaped by it, not only does the prosperity of millions . . . depend upon it, but our whole theory of life has long been influenced, consciously or unconsciously, by the general conceptions of the universe, which have been forced upon us by physical science. [Thomas Henry Huxley, 1880]

Science Empowers and Enriches

Huxley's statement on the value of science is even more valid today than when it was written more than one hundred years ago. Then, and increasingly so now, the pervasive influence of science on the quality of our lives makes an understanding of science central to our personal, national, and global welfare. With the accelerating pace of scientific discoveries and technological advances over the last century, knowledge of the methods and products of science has become ever more essential to full participation in contemporary American society. In addition to enhancing the minds and lives of individual citizens, science learning is

16 National Assessment of Educational Progress, *The Science Report Card: Elements of Risk and Recovery*, Trends and Achievement Based on the 1986 National Assessment (Princeton, NJ: Educational Testing Service, 1988): 4-17.

crucial to the social and economic development of our country. To understand and resolve the increasing number of societal problems related to science and technology, for example, the depletion or pollution of natural resources - our schools must produce a large majority of graduates who are literate about these issues and an increasing percentage of students who are both highly prepared and motivated for advanced careers in science.

From a broader perspective, there is growing concern over our country's future ability to compete in the global economy. A highly technological nation such as ours requires civic and educational leaders whose understanding of science and technology is sufficient to make decisions based on valid information and rational analysis. Our nation's economic growth and its place in world markets are determined in part by its ability to provide intelligent leadership in technological fields.

The State of Science Learning

It is widely believed that the condition of science education in the country needs improvement, and the results of NAEP's 1986 science assessment do not assuage this concern. In 1983, the National Science Board's Commission on Precollege Education in Mathematics, Science and Technology described the implications of neglecting science education:

> Alarming numbers of young Americans are ill-equipped to work in, contribute to, profit from and enjoy our increasingly technological society. Far too many emerge from the nation's elementary and secondary schools with an inadequate grounding in mathematics, science and technology. As a result, they lack sufficient knowledge to acquire the training, skills, and understanding that are needed today and will be even more critically needed in the 21st century.

Since this statement was made, as many as 100 national reports have been issued calling for greater rigor in science education and suggesting numerous reforms. The nation has responded by updating standards for school science programs, strengthening teacher preparation, increasing the use of assessments, stiffening graduation requirements, and implementing a wide variety of research efforts to deepen our understanding of science teaching and learning. Despite these efforts, average science proficiency across the grades remains distressingly low.

Trends for 9, 13, and 17-year-olds across five national science assessments conducted by NAEP from 1969 to 1986 reveal a pattern of initial declines followed by subsequent recovery at all three age groups. To date, however, the recoveries have not matched the declines.

- At age 17, students' science achievement remains well below that of 1969. Steady declines occurred throughout the 1970s, followed by an upturn in performance between 1982 and 1986;

- *At age 9 and 13, the declines were less sizable than those at age 17 and recovery began earlier, in the late 1970s. In 1986, however, average achievement at age 13 remained below that of 1970 and at age 9, simply returned to where it was in the first assessment.*

National expectations are high. Students are expected to complete their high-school studies with sufficient science understanding for assuming their responsibilities as voters and as efficient contributors in the workplace. In addition, school science is expected to prepared adequately for postsecondary science courses those students who are continuing their formal education. Unfortunately, these expectations have not been met. An examination of NAEP trends in science proficiency suggests that a majority of 17-year-olds are poorly equipped for informed citizenship and productive performance in the workplace, let alone postsecondary studies in science.

- *More than half of the nation's 17-year-olds appear to be inadequately prepared either to perform competently jobs that require technical skills or to benefit substantially from specialized on-the-job training. The thinking skills and science knowledge possessed by these high-school students also seem to be inadequate for informed participation in the nation's civic affairs;*

- *Only 7 percent of the nation's 17-year-olds have the prerequisite knowledge and skills thought to be needed to perform well in college-level science course. Since high-school science proficiency is a good predictor of whether or not a young person will elect to pursue post-secondary studies in science, the probability that many more students will embark on future careers in science is very low.*

These NAEP findings are reinforced by results from the second international science assessment, which revealed that students from the United States - particularly students completing high school - are among the lowest achievers of all participating countries.

- *At grade 5, the U.S. ranked in the middle in science achievement relative to 14 other participating countries;*

- *At grade 9, U.S. students ranked next to last;*

- *In the upper grades of secondary school, "advanced science students" in the U.S. ranked last in Biology and performed behind students from most countries in Chemistry and Physics.*

Given evidence from both the NAEP and international results that our students' deficits increase across the grades, projections for the future do not appear to be bright. The further students progress in school, the greater the discrepancies in their performance relative both to students in other countries and to expectations within this country. Because elementary science instruction tends to be weak, many students - especially those in less affluent schools - are inadequately prepared for middle-school science. The failure they experience in middle school may convince these young people that they are incapable of learning science,

thus contributing to the low enrolments observed in high-school science course. Unless conditions in the nation's schools change radically, it is unlikely that today's 9- and 13-year-olds will perform much better as the 17-year-olds of tomorrow.

The Status of Science Learning for "At Risk" Population

Students do not all arrive at the kindergarten door will equal opportunities and aspirations. Social and economic realities have begun to have an impact long before that time, and schooling does not serve to eradicate these inequities.

The NAEP data show substantial disparities in science proficiency between groups defined by race/ethnicity and gender.

- Despite recent gains, the average proficiency of 13- and 17-year-old Black and Hispanic students remain at least four years behind that of their White peers;
- Only about 15 percent of the Black and Hispanic 17-year-olds assessed in 1986 demonstrated the ability to analyze scientific procedures and data, compared to nearly one-half of the White students at this age;
- While average science proficiency for 9-year-old boys and girls was approximately the same - except in the physical science - a performance gap was evident at age 13 and increased by age 17 in most science content areas. At age 17, roughly one-half of the males but only one-third of the females demonstrated the ability to analyze scientific procedures and data;
- The marked edge in the physical sciences shown by boys at grade 3 increased at grades 7 and 11, but in the eleventh grade, the performance gap in physics was extremely large;
- The large difference in science performance by gender cannot be explained by differential course-taking patterns; in some cases, the proficiency gap between high-school-aged males and females actually increased with course-taking.

Since a higher proportion of Black and Hispanic children than White children come from homes of lower socioeconomic status, disparities in performance attributed to race/ethnicity may be due in large part to differences in such factors as parents' education levels and access to reading and reference materials in the home. In fact, recent research on mathematics achievement shows that when other school and home factors are controlled, students' socioeconomic status accounts for a large part of the performance gap. Economically disadvantaged students are likely to enter school at an educational disadvantage, because they appear to be behind their peers and are therefore placed in remedial classes. The consequence of this early tracking is that many of these

students are poorly prepared to pursue higher-level science and mathematics coursework when they get to high school.

In the case of performance disparities between male and female students, there is growing evidence of differential treatment and opportunities in science instruction. Teachers have higher expectations for boys than girls and ask them higher-level questions. Textbooks may also send the message that most of the notable accomplishments in science re attribute to White males. Because there are still relatively few female and minority scientists, students are unlikely to encounter them as role models.

While one would expect in-school experiences to contribute to students' participation and achievement in science, the NAEP data also suggest that some of the factors underlying performance differences may originate outside of the school. This appears to be particularly true for the performance gap by gender. In the 1986 assessment, females were substantially less likely than males to report science-related activities or experiences.

While the NAEP data cannot tell us what causes these differences there is evidence from other sources that sex - and race-role stereotyping are often major deterrents to the participation of female and minority students in science and science-related activities. For example, parents, peers, the media teachers, counsellors, and curriculum materials may give females and minority students the idea that only certain roles are appropriate for them. Within-and out-of-school experiences appear to reinforce one another in creating and perpetuating differences in achievement.

Research on teaching and learning indicates some approaches that appear promising for improving the participation of females and minorities in science. For example, to counteract the aversion toward physical science that girls seem to develop even before they enter school, elementary science should include an abundance of hands-on activities related to concepts in electricity, magnetism, and other areas, structured so that girls play an active rather than a passive role. In addition, appropriate role models should be provided through interactions with both male and female scientists of various racial/ethnic backgrounds, both in person and through textbooks, films, and other instructional materials.

Teacher education, both pre-service, should make teachers aware of the more subtle behaviours that communicate how expectations to particular students, and give them assistance in implementing instructional techniques that are effective with female and minority students, as well as White males. Finally, alternative mechanisms need to be developed to foster the skills that will prepare students for academic sequences in high school rather than curtail their opportunities.

Opportunity to Learn Science

Two distinct aspects of an opportunity to learn are the amount of time spent on instruction and the quality of that time. The first is a necessary but insufficient condition for the second; however, results from the 1986 NAEP science assessment suggest that neither condition of the opportunity to learn science is afforded our nation's youth.

- *More than two-thirds of the third-grade teachers responding to NAEP's 1986 teacher questionnaire reported spending 2 hours or less each week on science instruction; many spent more than that amount of time maintaining order and disciplining students in the classroom;*

- *Eleven percent of the third graders assessed in 1986 reported having no science instruction at the time of the assessment; in addition, one-third of the elementary students who were receiving instruction reported spending no time on science homework;*

- *All but 6 percent of the seventh graders reported taking some type of science course in 1986, but enrolment dropped substantially by grade 11. Only 58 percent of the eleventh-grade students were taking a science course at the time of the assessment;*

- *Approximately half of the teachers in grades 7 and 11 reported spending three hours or less providing science instruction each week;*

- *Of the seventh- and eleventh-grade students taking a science class in 1986, 12 to 16 percent reported spending no time on science homework each week.*

These findings are corroborated by recent literature in which teachers reported spending only an average of 18 minutes per day on science at grades K-3 and only about 29 minutes per day at grades 4-6. Across these grades, the amount of time spent was greatest for reading, followed by mathematics, then social studies and science - a ranking which had not changed since 1977. Thus, even for those students who are enroled in science classes, the amount of time actually spent on science learning appears to be minimal.

In addition, very few students in this country take advanced science course. Preliminary results of a follow-up transcript study of eleventh-grade students participating in the 1986 assessment indicate that while 90 percent of these graduating students had studies at least one year of Biology, only 45 percent had studied one year or more of Chemistry, and 20 percent that amount of Physics. Although these findings represent increases in science course-taking since 1982, enrolments generally remain low from an international perspective. Only about 6 percent of all high-school students in this country take advanced courses in Biology compared with 45 percent of the students in Finland and 28 percent of the students in English-speaking Canada. Similarly, students studying

advanced Chemistry and Physics represent a very small percentage of the total U.S. student population; by comparison, in other countries these students represent as much as one-sixth to one-fourth of the total student population.

The Relationship Between Amount of Science Instruction and Proficiency

A recent report issued by the National Academy of Science Committee on Indicators of Precollege Science and Mathematics Education reviewed the research literature linking instructional time and student learning; it concluded that at both the elementary- and secondary-school levels, the amount of time given to studying a subject is correlated with student performance as measured by achievement tests. The report also found that the amount of time spent on homework is correlated with student achievement, and that teachers' attention to homework affects its contribution to performance.

These conclusions are further reinforced by NAEP findings from the 1986 assessment, which suggest positive associations between science proficiency and the amount of time spent in science learning (i.e., through course-taking and homework), particularly among eleventh-grade students. It may be, however, that highly proficient students choose to take more courses or select more challenging courses that require more homework. Further, as previously noted, time spent in science classes per se cannot guarantee the quality of that instructional time. Although both common sense and empirical findings indicate that more time spent in science instruction will improve science learning - thus supporting reforms that are targeted toward reducing absenteeism, increasing science course-taking requirements, and assigning more homework - great care also must be taken to address the quality of that instructional time.

Because educational reforms implemented in the 1980s cannot be expected to have immediate impact and their full effects may not be noticeable for some time, the slight progress evidenced in the NAEP results may portend improvements for the future. It must be recognized, however, that improvements in average performance seen in the 1986 assessment were largely the result of students' increased knowledge about science rather than increased skills in scientific reasoning. This finding, coupled with the disappointing state of science education, suggests that current reforms tend to be aimed primarily at the symptoms rather than the disease. What has traditionally been taught in science may be neither sufficient nor appropriate for the demands of the future, necessitating reforms that go beyond increasing students' exposure to science and that center on implementing new goals for improving curriculum and instruction.

Science Learning in the 'Spirit of Science'

Embarking on fundamental reforms of science curriculum and instruction requires a reexamination of the conceptual underpinnings of science education. Science educators have maintained that hands-on and laboratory experiences should be an integral part of science instruction, explaining that it is appropriate for science teaching and learning to parallel the methods of investigation used by scientists to understand the natural world.

Results from the 1986 science assessment do indicate a positive relationship between students' use of scientific equipment and their proficiency in the subject, particularly at the eleventh-grade level, but cause-and-effect relationships cannot be addressed by NAEP data. Schools with laboratory facilities and other scientific equipment may be the wealthier schools, populated by advantaged students who tend to perform better in academic assessments. Disciplined research is needed to substantiate the impact of hands-on activities on science proficiency, and the appropriate role of these activities in science instruction.

Findings from the NAEP assessment also suggest positive associations between participatory classroom activities and science proficiency, and between attitudes toward science and students' proficiency in the subject. Again, while the NAEP data are suggestive, they by themselves do not permit the conclusion that more participatory activities or efforts to improve students' views of science will necessarily raise achievement levels for any given student population. Decisions to strengthen science education that may be suggested by the NAEP data must be firmly based on relevant research and experience.

Given these caveats, some aspects of science practice can be used to analyse the nation's science education program and reflect on NAEP findings. What are the features of the scientific enterprise that our science education system might emulate?

***Activities.** Procedures of investigation - such as observation, measurement, experimentation, and communication - allow the scientist to gain an understanding of natural phenomena. In addition, mental processes such as hypothesizing, using inductive and deductive reasoning, extrapolating, synthesizing, and evaluating information are necessary to scientific investigation, as are the less well defined but no less important skills of speculation, intuition, and insight. An effective science learning system would provide students with opportunities to engage in these activities, and encourage science teachers to model them in their classrooms.*

***Beliefs and Assumptions.** Scientists appear to operate in accordance with a set of beliefs about the natural world that guide their methods of inquiry and the knowledge yielded by these methods. For example, scientists believe a real world exists that can be understood;*

they assume that nature is not capricious and that events in nature have causes.

Implementing the methods of scientific inquiry yields knowledge about the natural world, contained in the form of facts, concepts, hypotheses, theories, and laws. These structures are characterised in part by scientist's beliefs, making it possible to communicate scientific knowledge, give it logical coherence, offer explanations, and make predictions. Yet another key aspect of the knowledge of science is its tentativeness: Scientist view findings not as final statements but rather as reasonable assertions about some distant, but seldom reached, truth.

Characteristics of Scientists. *Certain personality traits seem to characterize successful scientist, and these may provide additional guidance for determining the features of an effective science education program. Among the salient traits of successful scientists are curiosity, creativity, and dedication. Scientists ask questions about and are sensitive to the world around them. The critical nature of the profession requires a strong belief in one's ability to learn, and an ability to distinguish between productive and unproductive ideas. The joy of discovery is a driving force in scientists' professional lives; they are hungry for knowledge and recognition, and strive to achieve both.*

Elements of the Model in Light of NAEP Findings

The "spirit of science" model suggests that the most effective learners are those who are actively engaged in the learning process and accept responsibility for their own learning. In contrast, data from the 1986 NAEP science assessment indicate that by grade 11, almost half of the students have decided not to take any more science courses, few spend time on independent science-related hobbies or activities, and only about half think that what is learned in science class is useful in everyday life. This portrait is indeed far from the model.

The brief analysis of the scientific pursuit of learning also suggests the value of providing students with greater opportunities for observing natural phenomena both within and outside the classroom, and engaging them in measuring, experimenting with, and communicating data from the surrounding world. As active rather than passive participants in the learning process, students can strengthen their full range of mental processes, from formulating hypotheses, explaining observations, and interpreting data to other thinking skills used by scientists in their efforts to build understanding.

However, the NAEP data show:

- *Only about one-third of the seventh graders and slightly more than half of the eleventh graders reported that they were asked to hypothesize or interpret data in their science class at least on a weekly basis.*

- Only 35 percent of the seventh graders and 53 percent of the eleventh graders reported working with other students on science experiments at least on a weekly basis.

- Over half of the third graders and more than 80 percent of the seventh and eleventh graders reported never going on field trips with their science class.

- Sixty percent of the seventh graders and 41 percent of the eleventh graders said they never had to write up the results of science experiments.

- Only about 46 percent of the teachers of seventh or eleventh grade reported access to a general-purpose laboratory and only 64 percent of the eleventh-grade teachers reported access to a specialized laboratory for use in teaching science.

A classroom environment that emulates the "spirit" of science is characterized by collaboration between teachers and students to test knowledge that is gained and a willingness to modify this knowledge in light of new evidence. This setting encourages students to wonder about the world around them and actively seek to understand it. It build their thirst for knowledge and strengthens their sense of responsibility to learn. Teachers provide role models for students and stimulate their curiosity. Yet numerous studies of the last few years - for example, John Goodlad's A Place Called School - have indicated that most teaching, including science teaching, is instead dreadfully dull.

For the classroom to mirror the real-world practice of science, the teacher should be an active model, spending less time lecturing and more time engaging students in hands-on activities and asking open-ended questions than do teachers in general. In contrast, students in the 1986 NAEP science assessment reported few opportunities to explore natural phenomena directly or engage in discussions about the limited experiences that they did have. They revealed a preponderance of class time spent listening to teachers' lectures; in addition, limited information on school curriculum suggests that scientific content appears to be largely textbook - and workbook - driven, reflecting little - or not at all - the recent technological advances in the domain of science.

Science Curriculum

To provide curriculum, instruction, and facilities appropriate to the demands of science teaching and learning, it is clear that a number of substantial changes are needed. The need for greater availability of classroom laboratory facilities is undeniable. The 1985-86 National Survey of Science and Mathematics Education found that while most teachers believed that laboratory classes were more effective than non-laboratory classes, lectures were reported as their primary teaching technique. However, this paradox may be partially explained by the fact that a substantial percentage of teachers do not have access to

adequate laboratories, science equipment, supplies, and other resources needed for teaching science.

Perhaps even more crucial than greater access to laboratory facilities are the more fundamental, but less obvious, changes associated with teaching and curriculum. Cross-cultural studies shed some light on the direction that is needed, revealing significant differences between science curricula in this country and those in Japan, China, East and West Germany, and the Soviet Union. In these five countries, science content is more closely linked to the requirements of modern industrial society, and the instructional approach is to teach an array of disciplines over a period of years, maintaining continuity across the grades. In comparison, the prevailing practice for public school students in the United States is to take one science subject for one academic year and then move to another discipline the following year - sometimes referred to as the "layer-cake curriculum."

Before sweeping changes in curriculum are adopted, research is needed to establish the effects of the content, sequence, and amount of science instruction on students' science learning. Because education is cumulative, perhaps the best way to understand how curriculum and course-taking affect student knowledge and competence in science is o conduct longitudinal studies that follow students through at least one year of science instruction. One difficulty in conducting this type of research, beyond cost, is to describe in sufficient detail the content and other attributes of the science curriculum actually presented to students, beyond the course title and textbook used. By examining important aspects of both the intended and implemented curriculum - and relating these "opportunity to learn" data to students' mathematics achievement - the Second International Mathematics Study offers a useful model for research in science learning.

Science Instruction

In the ideal science classroom, students would have abundant opportunities to question data as well as experts, to design and conduct real experiments, and to carry their thinking beyond the information given. They would identify their own problems rather than always solving problems presented by tests, teachers, or other authoritative sources. Much of their problem-solving might also be in the form of practical experience. Through these experiences, students would come to realize that knowledge in science is tentative and human-made, that doing science involves trial and error as well as systematic approaches to problems, and that science is something they can do themselves. To provide such instruction, teachers need to be prepared with a keen understanding of the nature of science, rather than just its requisite facts. Like their students, few teachers have had opportunities to conduct real experiments under real conditions; therefore, as a starting point, teacher education should provide opportunities for prospective science teachers to work with students at a variety of grade levels and in a variety of settings. The traditional one-semester methods course required of prospective teachers should give way to two or three

semesters of coursework in this area, using video and audio tapes, intense feedback from professionals, and methods instructors who model the types of instruction desired.

At the same time, courses in the history, philosophy, sociology, and applications of science should be required of pre-service science teachers, enabling them to develop a rationale for teaching science that integrates their goals for teaching science and what is known about effective teaching practices, the nature of science, and the ways in which children learn - as well as methods of evaluation that are compatible with all of these. Teachers with such a rationale are prepared to be flexible and can integrate research into classroom practice. These teachers approach teaching scientifically and provide models of active inquiry for students. Perhaps teachers with such rationales would rely less on textbooks and would find them more useful as reference materials than as curriculum guides. As a result, students may come to see that science class is a place where the role of student and teacher alike is to raise questions and investigate possible answers and to explore new techniques and methodologies.

Teachers with a new rationale for science instruction would not only be competent and consistent, but also concerned with domains beyond knowledge - including the role of career choice, creativity, attitudes, thinking, application, and communication in science instruction. Students successful in these domains would more closely approach the levels of science literacy called for by virtually all educators concerned with the current state of science education.

Conclusion

Evidence from NAEP and other sources indicates that both the content and structure of our school science curricula are generally incongruent with the ideals of the scientific enterprise. By neglecting the kinds of instructional activities that make purposeful connections between the study and practice of science, we fail to help students understand the true spirit of science, as described in these pages.

In limiting opportunities for true science learning, our nation is producing a generation of students who lack the intellectual skills necessary to access the validity of evidence or the logic of arguments, and who are misinformed about the nature of scientific endeavors. The NAEP data support a growing body of literature urging fundamental reforms in science education - reforms in which students learn to use the tools of science to better understand the world that surrounds them.

6 The 1985-86 National Survey of Science and Mathematics Education

This survey is essentially a repeat of a survey first conducted in 1977 and documents changes in a variety of indicators of science and mathematics education in the United States during the past decade. The survey was based on

questionnaires distributed to a sample of school principals and science and mathematics teachers.

The issues covered in the report[17] are as follows:

Time spent in Elementary science and mathematics instruction;
Science, mathematics and computer science course offerings;
Textbook usage and teachers' perceptions of textbook quality;
Objectives of math and science instruction;
Use of computers and calculators;
Teacher characteristics and preparation;
Perceptions of teachers' qualifications;
Inservice education and other forms of teacher assistance;
Availability of instructional resources;
Problems in science and mathematics instruction;
Teacher supply and demand.

The report contains no integrative summary nor highlights; it does, however establish a broad national picture of aspects of science and mathematics educational practice in 1986 and provides for comparison with the conditions of a decade earlier.

7 The AIP 1986-87 Nationwide Survey of Secondary School Teachers of Physics

HIGHLIGHTS SUMMARY[18]

- *623,000 students were enroled in high school physics in the spring 1987 semester. Approximately 20% of all high school graduates take physics;*
- *66% of all high schools offer physics every year, and another 17% offer the course in alternate years. 96% of all high school students attend schools where physics is available;*
- *90% of all public high schools with physics have only one physics teacher and 82% offer only the basic first year course in physics. Only among the largest schools is it common that honors, advanced placement, and second-year classes are offered;*

17 Iris Weiss, *Report of the 1985-86 National Survey of Science and Mathematics Education*, Research Triangle Institute, 1987.

18 Michael Neuschatz and Maude Covalt, *Physics in the High Schools*, Findings from the 1986-87 nationwide survey of Secondary School Teachers of Physics (New York: American Institute of Physics, 1988).

- *Public schools with large concentrations of students from minority groups and schools located in the South enroll a lower than average proportion of students in physics;*

- *Over a third of public school teachers report an increase in the proportion of students taking physics over the past five years, while fewer than one in ten report a decline;*

- *Teachers seem to place greater stress on transmitting the basics in their physics classes. Almost three-fourths give top priority to the goals of teaching basic physical concepts and developing general problem-solving abilities;*

- *Major complaints were inadequate funding for supplies and lab facilities;*

- *Approximately one-third of the teachers could be described as having their primary specialty in physics, while another third began their career in another field but have taught physics regularly over the subsequent years. The remaining third can be classified as only occasional teachers of physics;*

- *In spite of their generally smaller size, non-religious private schools, Catholic Schools, and schools affiliated with "mainstream" Protestant denominations seem to put as much or more stress on physics instruction than public schools do. Schools affiliated with fundamentalist Christian and orthodox Jewish groups, on the other hand, are much less likely to include physics in their curricula, and, where they do teach it, offer only the basic first-year course;*

- *The three sets of factors which seem to have the greatest impact on the presence and robustness of physics programs in the high schools are: a) school size and geographic location; b) demographic character of student body, especially socio-economic and racial composition; and c) the level of commitment of the school administration to rigorous and sophisticated science instruction;*

- *While high physics enrolments and quality instruction seem to have a mutually reinforcing effect, even small schools can maintain robust physics programs where administrative support in hiring, funding, and encouraging professional growth is strong and where graduation requirements encourage science-taking;*

- *High enrolments seem to permit more varied course offerings in physics and allow teachers to specialise in the field, further improving program quality and encouraging more students to enroll. Widespread physics-taking and provision of higher-level courses for advanced students thus appear to be complementary rather than competing goals;*

- *International comparisons just becoming available seem to corroborate this view. Countries where most or all senior level secondary students take physics also can boast the highest achievement levels*

for the most advanced students. Even taking into account the fact that the United States retains a much higher percentage of students to the point of graduation, our country fares poorly in terms of both the proportion of students exposed to physics and the performance of those enroled in the most advanced courses offered.

8 Educating Scientists and Engineers: Grade School to Grad School[19]

Summary

American schools, colleges, and universities have the capacity to provide enough scientists and engineers to meet the Nation's needs. Historically, students and institutions have satisfied changing market needs, as evidenced by the response of engineering enrolments to the semiconductor industry boom of the late 1970's. However, many researchers, employers, and policymakers are concerned that future supply will be inadequate. In the early 1990's, the Nation will experience a decline in the number of college-age students, although some increase can be expected before the turn of the century. More important, fewer students, particularly those white males who have been the mainstay of science, seem to be interested in science and engineering careers. Women's interest in science to have plateaued. Non-rising for a long time, seems to have plateaued. Non-Asian minorities, traditionally poorly represented in science and engineering, will form a steadily increasing proportion of American schoolchildren.

Despite these changes, OTA concludes that shortages of scientists and engineers are not inevitable; the labor market will continue to adjust, albeit with transitory and perhaps costly shortages and surpluses. The Federal Government may need to play a more active role. Rather than trying to direct market responses, policy can aim to prepare a cadre of versatile scientists and engineers for research and teaching careers, invest in an educational system that creates a reservoir of flexible talent for the work force, and ensure opportunities for the participation of all groups in science and engineering.

The Federal Government has had both direct and indirect effects on the education of scientists and engineers, but it is only one of many actors in the system. The Federal role in science and engineering education is most significant at the graduate level, more diffuse at the undergraduate level, and small in elementary and secondary education.

Federal investment in science and engineering education and training is undertaken for many reasons; there is no single objective or mission. One class of investments is in direct support of graduate students and

19 U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School*, OTA-SET-377 (Washington, D.C.: U.S. Government Printing Office, 1988): 1-3.

production capacity at blue-chip universities. Other investments are made in newer, developing colleges and universities with growth potential, and in undergraduate and precollege education. Federal support is spread across different types of institutions and students, partly because of the uncertainty of payoffs, and partly to ensure equality of access and geographical balance. Both short-and long-term investments are necessary in a marketplace where demographics, economics, and technology constantly change the criteria for success in education for the work force.

The educational process from grade school to graduate school is 20 years long. This means there are many possible Federal options for enriching the future supply of scientists and engineers. It is difficult, however, to distinguish which would have the most impact. At each level of the educational system, there are many choices for action. Few measures guarantee predictable effects in the relatively short term, most are most speculative and longer-term possibilities. Just as there are no imminent crises in replenishing the science and engineering work force, there are no quick fixes.

This assessment:

- *examines the forces associated with elementary and secondary education that shape the talent pool;*
- *traces pathways to undergraduate and graduate education in science and engineering, and;*
- *presents a discussion of policy areas for possible congressional action, developed under two strategies labeled "retention" and "recruitment."*

Two Federal management issues are also identified. These are leadership and coordination among Federal agencies, and evaluation of trends and outcomes to define future policy actions that will improve the reach and content of science and engineering education. The overarching policy issue is whether the Federal Government allows the market for scientists and engineers to take its course or attempts to intervene more boldly.

The two broad strategies of retention and recruitment complement each other and would operate best in tandem (see table).

Policy Options To Improve Science and Engineering Education

Recruitment – Enlarge the Pool

- *Elementary and secondary teaching:* encourage and reward teachers; expand support for preservice and inservice training.
- *School opportunities:* reproduce science-intensive schools; adjust course-taking and curricula; review tracking; and revise testing.
- *Intervention programs:* increase interest in and readiness for science and engineering majors; transfer the lessons from successful programs; encourage sponsorship from all sources.
- *Informal education:* increase support of science centers, TV, fairs, and camps.
- *Opportunities for women:* enforce Title IX of the Education Amendments of 1972 and provide special support and intervention.
- *Opportunities for minorities:* enforce civil rights legislation and provide special support and intervention.

Retention – Keep Students in the Pool

- *Graduate training support:* "buy" Ph.D.s with fellowships and traineeships; these people are most likely to join the research work force.
- *Academic R&D spending:* bolster demand and support research assistants, especially through the mission agencies.
- *Foreign students:* adjust immigration policies to ease entry and retention.
- *Undergraduate environments:* support institutions that reward teaching and provide role models, such as research colleges and universities, and historically Black institutions.
- *Hands-on experience:* encourage undergraduate research apprenticeships and cooperative education that impart career skills.
- *Targeted support for undergraduates:* link need- or merit-based aid to college major.

Strengthen Federal Science and Engineering Education Efforts

- *National Science Foundation as lead science education agency:* underscore responsibility through the Science and Engineering Directorate for elementary through undergraduate science programs.
- *Federal interagency coordination and data collection:* raise the visibility of science education and the transfer of information between agencies and to educational communities.

The retention strategy is designed to invigorate the current science and engineering work force by reducing attrition of undergraduate and graduate students. Such short-term retention programs could increase output of scientists and engineers within a few years. In contrast, recruitment is a long-term strategy to enlarge the base of potential scientists and engineers by recruiting more and different students into science and engineering. Such a strategy entails working with schools and colleges, along with children, teachers, and staff, to renovate elementary and secondary mathematics and science education.

If the Nation wants more scientists and engineers relatively quickly, then retaining college and graduate students in science and engineering is the most useful policy strategy. Many able students leave science during college, after earning baccalaureate degrees, and during graduate school. Only about 30 percent of baccalaureate science and engineering graduates enter full-time graduate study, and nearly half of science and engineering doctoral candidates never earn Ph.D.'s. Some loss is inevitable (and, indeed, beneficial to other field), but those who leave unwillingly and prematurely are a rich resource that could be tapped. Because attrition rates are so high and the population of research scientists and engineers is relatively small, slight improvements in retention could increase significantly the number of scientists and engineers in the work force. Federal policies could work at all levels to retain more of these able, interested students in the pool.

Many factors affect students' career choice and persistence in science and engineering: interest and aptitude; perceptions about careers gleaned from university faculty, peers, and jobs; and anticipated earnings and other, nonmonetary rewards. Students considering academic careers must also weigh the burden of undertaking and financing graduate training. The Federal Government affects these career decisions through targeted support of students, universities, and research, and through its pervasive influence on the American economy and research agenda. The extend and form of Federal support for students, particularly graduate students, affects the attractiveness of further study. Federal research and development (R&D) support and national missions (e.g., in health, space, defence) shape students' perceptions of the job market for scientists and engineers, as well as the environments in which students are educated.

Many of the policies discussed in this report involve established mechanisms that could be expanded effectively. There are prepared college graduates and graduate students who, with the proven incentives of fellowships and R&D supported jobs, could be attracted to science and engineering.

The basic goal of recruitment is to expand and improve the talent pool. The years to do this are elementary school through the first years of college. A particularly critical time is 6th through 12th grade, when course-taking becomes more specialized and career plans are formed. Policies to expand the mathematics and science talent pool differ from those to accelerate or improve the education of a small, science-oriented population. Students who take early, enthusiastic likings to science and

mathematics can be served differently from those whose interests are still developing.

For all students, the content and quality of their elementary and secondary education determine their academic preparation for college, their likelihood of graduating from college, and their ability to derive the greatest benefit from a college education. Better high school graduates mean better college graduates, and ultimately better scientists and engineers. Increased participation for those students outside the traditional stereotype of college-bound science or engineering majors, such as many minorities and women, must begin with early changes in their preparation, awareness, and interest. They must first be prepared for and drawn into college and science majors before they can respond to graduate and R&D programs. The continuing low proportion of these groups in science and engineering indicates that the current educational system and career incentives must be made to work better. The end of expansion and transition to a steady state of enrolments and research funding will require universities, employers, and the Federal Government to adjust their models and mechanisms of science and engineering recruitment.

There are two demonstrably successful ways to recruit young people to science and engineering offer special science and mathematics educational enrichment programs tailored to selected students, and give all students good, enthusiastic teaching. An area of lively innovation is informal education - science museums, television programs, camps, and other experiences outside the formal school system.

In the near term, policies can only be implemented with existing teachers, schools, textbooks, and equipment, in a system with multiple educational objectives. In the longer term, substantial improvements in recruitment might come through full-scale revision of elementary and secondary curricula, tracking, testing, and course structure. Such sweeping change should be undertaken with all students and all purposes of education in mind (nor just science and engineering), and will be hard to achieve given the scale of American education and the inertia of the existing systems.

The health of the U.S. economy, technological changes, and shifting government priorities, none of which can be projected with any useful degree of accuracy, all affect future demand for scientists and engineers. The demand has increased since World War II, and most analysts expect that growth to continue; but growth will vary significantly from field to field. The complexity of analyzing changes in demand for the relatively small science and engineering work force confounds forecasts, especially at the level of individual fields. Federal actions, because of their pervasive effects on the economy and on the size and location of R&D activities, have strong effects, both direct and indirect, on the demand.

Although comprising only 4 percent of American workers, scientists and engineers have specialised skills that are vital to the national welfare: they widen human understanding by doing basic research and by

teaching, they develop and apply new technologies of every king, and they keep the national physical infrastructure and manufacturing base running smoothly. Other trained as scientists and engineers, but not actively employed in research or product development, also contribute to our national well-being in other occupations. Historically, the demand for scientists and engineers has been rising. The Nation is well advised, therefore, to seek an adequate supply of people prepared for science and engineering careers.

▪ Provincial Studies (Canada)

In recent years, an increasing number of provincial ministries of education have begun to conduct regular assessments of their school programs, including science and mathematics.

1 The British Columbia Science Assessment, 1986

The province whose program assessments have become the model for several others is British Columbia. In this province, all areas of the curriculum are reviewed on a 4-year cyclical basis. Thus, for example, science (at grades 4, 7 and 10) has been reviewed in 1978, 1982, and most recently in 1986. The major purposes of the overall assessment program are to:

1. *Inform professionals and the public of some of the strengths and weaknesses of the public school system;*
2. *Assist the Ministry, school districts, and schools in decisions relating to the development, review, modification, revision, and implementation of existing curricula and supporting instructional resource materials;*
3. *Assist the Ministry in decisions concerning allocation of resources;*
4. *Identify areas of need, and provide directions for change in both pre-service and in-service teacher education;*
5. *Provide directions for educational research;*
6. *Monitor student learning over time;*
7. *Provide the province, school districts, and schools with information which can be used to maintain strengths and overcome identified weaknesses.*[20]

The latest science assessment was designed, within this general framework, to examine the following issues:

1. *To what extent are students in Grades 4, 7 and 10 achieving the selected goals and objectives which are specified in the current science curriculum guides?*

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20 British Columbia, *Science Assessment, 1986*, Summary Report (Victoria: Ministry of Education, 1986): 1.

2. *To what extent have levels of achievement and attitude changes when compared to the achievement reported in the 1982 Science Assessment?*

3. *How does the achievement of B.C. students compare to the achievement of students in other jurisdictions and to the achievement of B.C. students historically?*

4. *What is the context within which science education is conducted in B.C.?*

5. *What recommendations to enhance student performance can be derived from these data and directed to appropriate groups and individuals?* [21]

The assessment saw 96,000 students complete achievement surveys and attitude scales in the following six domains of the curriculum:

- science processes;
- knowledge: recall & understand;
- application of science concepts;
- critical & rational thinking;
- technology & the nature of science;
- safety.

While a detailed analysis of the results of the assessment is beyond the scope of this report, it is perhaps worth noting that the B.C assessment concludes that while student performance is actually improving over time in science, the ratings of the interpretive panel were often the same or even went down. The report concludes:

> What seems to be occurring is that societal expectations of students is increasing faster than student performance is increasing. This may, at least in part, explain the popular belief that students of today are not as good as students of yesteryear.[22]

This echoes the finding in Ontario mathematics reported earlier and raises interesting questions about the public's objectivity in its assessment of education – or, on the other hand, about the breadth of the public's assessment, compared with that of the objective assessments of student achievement.

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21 *Ibid.*, p. 2.

22 *Ibid.*, p. 22.

2 Alberta Diploma Examinations Program and Triennial Assessment

In addition to an assessment program similar to that of British Columbia, Alberta has regular departmental examinations for all students in their final year of high school. These "Diploma Examinations" comprise 50% of a students final mark in those courses examined. Additionally, Alberta Education publishes a report on the results of each year's diploma examinations (although the marks of individual students are, of course, not made public).[23]

The provincial assessment program tests students in grades 3, 6 and 9 on a four-year cycle. In 1988 tests in social studies, language arts and mathematics were administered. In mathematics in 1988, of the 25,290 students writing the examination, 88.9% "received marks at or above the aceptable provincial standard while 24.3% had results at or above the outstanding level."[24] The press release also points out that overall achievement in grade nine mathematics was higher than in 1984, the last testing year.

In addition to these official assesament programs conducted by the Alberta Government, the University of Alberta administers what it calls a "Physics Advisory Examination" to students entering first-year physics.[25] While this examination was initiated over a decade ago, in the absence of provincial examinations, to give professors an idea of the degree of preparedness of their students in math and reasoning abilities, it is still continued. And it appears to show that students' scores on the PAE improved at about the same time that provincial examinations were instituted. The authors of this short report also concede that the predictive value of the PAE in relation to physics achievement in first year courses is not great (the correlation between the two is running at about 0.34).

3 Science for Saskatchewan Schools

The national study of science education in Canada, conducted by the Science Council of Canada and concluded in 1984, coincided with a general review in Saskatchewan of the education system, which recommended a K-12

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23 For example: *Diploma Examinations Program. Provincial Report*, June 1988 Administration, Edmonton: Alberta Education, 1988.

24 Alberta Education, Press Release, December 2, 1988.

25 Wytse Brouwer and David Austen "The Math and Physics Backgrounds of First-Year University Students," *Alberta Science Education Journal*, vol. 22, no. 1 (April 1988): 36-39.

program policy framework based on a core curriculum for all students. In that context, major reviews of selected areas of the curriculum were undertaken of which one in science was conducted by Dr Paul Hart of the University of Regina.[26]

This comprehensive study of science education in Saskatchewan included reviews of the research literature in such fields as: the nature of science, teacher education, science-technology-society-environment; science and the learner. It examined the goals of science education, instructional strategies, methods of evaluating students, programs and teachers, the integration of science with other areas of the curriculum and many other related matters.

Finally after preparing draft suggestions and engaging in an extensive field study in which opinions on these suggestions were sought from professional educators and others throughout the province, Dr Hart developed his final recommendations under the following headings: Curriculum resources; Curriculum leadership; Human resources; Instructional resources; External resources; Research resources. The Government of Saskatchewan is presently implementing a number of these recommendations.

4 Manitoba Science Assessment, 1986

The Manitoba 1986 science assessment, like those of B.C. and Alberta, is the second of a sequence of assessments the first of which took place in 1980.[27] It also surveyed student achievement at grades 3, 6 and 9, for purposes very similar to those of the other Western provinces. In 1986, however, unlike previous assessments, the study included a survey of teachers of science at grades 1-6 and a comparison test using items from the 1980 assessment (a special test administered in 1985). The major categories of the assessment framework were as follows:

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26 Paul Hart, *Science for Saskatchewan Schools: Field Study Report* (SIDRU Research Report No. 6) and *Science for Saskatchewan Schools: A Review of Research Literature, Analysis and Recommendations* (SIDRU Research Report No. 7) Regina: Saskatchewan Instructional Development and Research Unit, 1987.

27 *Manitoba Science Assessment, 1986*, Final Report and Summary Report (Winnipeg: Manitoba Education, 1986).

A. CONTENT OF SCIENCE
1. Facts
2. Terminology
3. Concepts/relationships
4. Theories and conceptual schemes
5. Explanation of physical phenomena
6. Trends and sequences

B. PROCESSES
7. Observing and Classifying
8. Measuring/Quantifying
9. Identifying, Collecting, Interpreting, Reporting data
10. Making inferences/Hypothesizing
11. Building, Testing, and Revising Theoretical Models

C. SKILLS FOR SCIENCE
12. Skills using laboratory equipment
13. Skills associated with study

D. PROBLEM-SOLVING AND DECISION-MAKING
14. Cognition
15. Following instructions/Using algorithms
16. Using inquiry techniques

E. ATTITUDE TOWARD SCIENCE
18. Enjoying science
19. Valuing science
20. Adopting attitudes of science
21. Making career decisions

F. SCIENCE AND SOCIETY
22. Science in Canada
23. Health, Nutrition and Agriculture
24. Environment
25. Energy
26. Recreation

G. NATURE OF SCIENCE
27. History of science
28. Philosophy of science

The following is an overview of the results of the 1986 assessment:

By the time Manitoba public school students have finished their grade 3 education they should have acquired a satisfactory knowledge of the content and processes of science consistent with their grade level. However, the assessment results reveal that grade 3 students often had

difficulty providing complete and precise written responses and that the concept of providing more than one answer to a single question was generally not an experience with which they were familiar. With respect to the processes of science, these students did well but had a fair degree of difficulty with items involving measurement. The performance component indicates that these children were enthusiastic about science but were not yet familiar with many aspects of the inquiry approach.

Students who have completed the ***grade 6*** *science curriculum in Manitoba schools were doing acceptably well in the categories which require fairly conventional lower-level thinking skills and emphases but were not doing well in application, synthesis and analysis and in areas of more recent emphasis such as Applications of Science to Society and the Nature of Science. In the affective domain, these students seemed to favour science generally but had difficulty in identifying the value of science. Grade 6 pupils had difficulty with written responses and explanations. These students experienced the greatest difficulty in the conceptual areas involving the Physical Sciences and the Earth Sciences. They were enthusiastic about laboratory investigations but showed evidence of much weakness in their ability to use inquiry techniques.*

The comparison between grade 8 students in 1980 and 1985 shows that students did less well in 1985. This almost certainly affected the grade 9 students' written and performance results in the 1986 assessment. ***Grade 9*** *students believed that science is an important subject but this positive attitude did not translate into satisfactory achievement. While this large assessment component had its bright spots, overall it was poorly done. The written and performance results indicate that grade 9 students did most poorly on the basic experimentation processes of observing, hypothesizing, identifying the cause and effect variables and in controlling variables. Concepts from Physical and Earth Sciences seemed to present the greatest difficulty for students at this grade level. Written responses were more of a problem than objective items.*[28]

5 Ontario Science Education Report Card

Following the Second International Science Study (reported earlier) the Ontario Ministry of Education commissioned an analysis of the province's standing in science education in relation to the other provinces.[29] As with the earlier report on SISS, only the English language components of SISS were available for this comparison. The study thus excludes Franco-Ontarians who were assessed along with Quebec and with Francophones elsewhere in Canada. The following are the personal interpretive comments of the author of that report. While they

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28 *Manitoba Science Assessment, 1986*, Summary Report, op. cit., p. 4.

29 F. Michael Connelly, *Ontario Science Education Report Card: Canadian National Comparisons* (Toronto: Ontario Ministry of Education, 1987). The highlights are taken from chapter 6.

are based on the SISS study, they should not be taken as representing a broad national consensus, therefore.

The Teaching Force

Over one third of all Canadian educators are found in Ontario. The number of educators in Ontario is 70 times that of the smallest province.

Secondary school teachers have stronger backgrounds than do elementary teachers. Roughly 65 percent of elementary school teachers have university degrees, some 20 percent less than those in the secondary schools.

The educational backgrounds of Ontario Grade 5 teachers show extremes. Twice as many Ontario Grade 5 teachers have no science courses in their backgrounds as compared to those in the Western and Eastern provinces. But far more Grade 5 teachers in Ontario than in the East and the West have a science specialization.

At Grade 9 over a quarter of the teachers have no science background although close to a half have a science major.

At Grade 12 Ontario has the largest number of teachers (8%) with no science background although 86% have a science major.

Science Teacher Professionalism

Ontario science teachers are a professionally oriented group. There are nine provincial and three national science teachers' organizations to which they may belong.

The most important of these is the Science Teachers' Association of Ontario which plays an increasingly active role in Ontario science education policy.

Research in Science Education

Ontario has a poor record of research in science education, given the number of faculty members devoted to science education throughout Ontario universities.

Policy Documents

There is very little similarity from province to province in the kind of documents used to express science goals and content.

The specific goals of science are relatively common across the country but the specific content outlined to achieve those goals varies considerably.

The degrees of commonality across the country in the science curriculum is low in the elementary school and comparatively high in the secondary school.

Biology shows the least commonality at all levels across the country.

The Eastern provinces tend to prescribe a larger proportion of the science curriculum than do the Western provinces. Ontario shows the most variation, with a low level of prescription in biology and a high level of prescription in chemistry.

Student Enrolments

In Ontario, biology and chemistry are selected by about equal numbers of students. Physics is the least popular secondary school subject.

Ontario has the best balance in enrollment among the sciences at the secondary school level of all the provinces.

On a percentage basis, Ontario appears to attract a larger percentage of its students into science than do other provinces.[30]

Student Achievement

Ontario achievement is below the national average in Grade 5 and Grade 9 and slightly above the national average at the senior secondary level. Compared to the highest achieving province in Canada, Ontario is about 4 percentage points lower in Grade 5 and over 5 percentage points lower in Grade 9. At the senior secondary level, Ontario is a little less than 2 percent below the highest performing provinces.

Ontario was the highest achieving province in one instance: chemistry, in senior secondary school. In grades 5 and 9 and senior secondary physics and biology the highest achievement scores were recorded by students in one of the Western provinces.

Ontario did not have the lowest achievement scores in any of the tests. An eastern province was lowest in all but one case, senior secondary school chemistry, where one of the western provinces had the lowest average achievement score.

Biology students outscore chemistry and physics across the country. The spread is slightly larger in Ontario than it is in either the highest or lowest performing provinces or the national average. Also the difference

30 Ibid, pp. 66-69.

between the physics score and biology score is greatest in Ontario, meaning that in comparison with other subjects physics students are doing poorly in Ontario compared to the rest of the country.

Ontario is the top-performing province in senior secondary chemistry. But at Grade 5 Ontario's chemistry sub-score is comparatively poor.

Male and Female Achievement

Males outscore females on average in Ontario and across the country. The differences, however, are not as large as some might have imagined.

Females outscored males at only two points throughout the Canadian science curriculum: in Grade 5 in the lowest achieving province and at the senior secondary level in biology in an average of all the provinces.

There is a greater Ontario difference between the sexes at Grade 5 than for either the highest or lowest performing provinces.

The greatest discrepancy between the sexes in Ontario secondary schools is in physics.

Student Attitudes to School and to Science

Student attitudes to school are high in Grade 5, drop sharply in Grade 9 and then more or less hold firm for Ontario students.

Ontario student attitudes are, in general, more positive than they are in the rest of Canada although Ontario comes out below the national average on the question of how much education students want.

Student attitudes to science subjects are not as positive as are their overall attitudes to school.

Over one fifth of the Grade 5 students are bored in school; the percentage increases in Grade 9.

There are sharp differences in how much students like the Senior Secondary science courses in which they are registered, with biology enjoyed the most and physics the least.

Valuing Science

Generally speaking, students have an overwhelmingly positive attitude to the value of science to society and to themselves.

Biology students at the senior secondary school level think biology is more relevant to everyday life than do chemistry and physics students.

Male and Female Attitudes to School and to Science

Females have a consistently more positive attitudes to school than do males at all levels.

The average males attitude to science is more positive than is the average female attitude. However, this is made up entirely of large differences in favour of males in physics. females actually show more positive attitudes to science in biology and chemistry.

Science Laboratories

Ontario is poorly equipped with science laboratories in Grade 5. Five times as many schools in the highest performing canadian province have science laboratories in their Grade 5 schools.

Ontario's laboratory situation has been rectified at Grade 9 and at the senior secondary school.

Ontario has a poor record with respect to laboratory technicians for teaching science. Ontario is at about the national mean in this respect at Grade 9, but by the senior secondary schoo' Ontario compares poorly with the top-performing provinces and with the national average.

Curriculum Decision Making

Ontario is unlike any other Canadian province in the degree to which curriculum decision making is decentralized. Both the high and low achieving provinces are more centralized than is Ontario. It is only in Ontario that teachers and school principals have a significant role to play. Boards of education also play a more important science curriculum role in Ontario than in any other province.

A General Summary

Ontario students have positive attitudes to school and to science but their achievement is not as high as might be expected of the richest province in Canada. Ontario shows innovativeness in curriculum decision making and exhibits more confidence in its local personnel than do other provinces.

6 Québec

Québec was a major participant in the Second International Science Study (described earlier) but, unlike Ontario and the other predominantly English-speaking Provinces, its participation was independently planned and undertaken.

The study was coordinated by M. Gilles Dussault, who also prepared a special report science education in Québec schools, based on data from the study.[31]

This study contained some surprising observations concerning the state of science education in Québec. In the area of student performance, Québec's grade 5 students ranked fourth among their peers from 16 other countries, only just behind Japan, South Korea and Finland. However, by the third year of secondary school, their performance had slipped to seventh and was behind the equivalent (grade 9) students from English-speaking Canada. Students in the final year of secondary school performed worst of 13 nations in general science, physics and chemistry. In biology, things were only slightly better, since U.S. students had even lower marks.

The results for the final year of secondary school must, however, be regarded with some skepticism. Care was not taken to distinguish, on a comparative basis, age and specialty groups. The Québec secondary school system graduates students one year before most other national secondary systems, rendering direct comparison problematic, the students examined being one year younger in the case of Québec. Further, Québec's student population tested was wider than that of other countries, specialisation having already occurred in some of the latter.

The low levels of performance may be related to the "thin" character (lacking in content) of the science programs, as described by Dussault. This characterization is not, however, shared by either the Ministère de l'Éducation du Québec or the Conseil supérieur de l'éducation. Nonetheless, it is also significant that more than 20% of the science teachers were not teaching in their own area of specialisation and that over a quarter of the teachers surveyed stated that their students never do practical laboratory work. Dussault's study also showed that the average third-year student in a Québec secondary school spends only 5.2 hours per week in out-of-class academic study in all subjects (and this only rises to 6.1 hours in Secondaire V).

7 Conclusion

These are the only provincial assessments that were available at the time of writing. Newfoundland has a Commission on Mathematics and Science Education in Schools (Commissioner: Dr Robert Crocker) whose report, available only since the end of this mandate, has not been analyzed here.

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31 Gilles Dussault, *L'enseignement des sciences dans les écoles secondaires du Québec. Bilan, recommandations et interrogations*, (Montréal: Sommet québécois de la technologie, octobre 1988).

It is of doubtful validity or value to attempt to synthesise the wide variety of studies of science and mathematics education in such a broad variety of jurisdictions that have been carried out for an equally l oad variety of purposes. The present report thus moves to an analysis of the second area of concern, namely the variety of initiatives being proposed and undertaken to improve science and mathematics education in the United States and Canada.

Part B Initiatives Being Taken to Improve Science and Mathematics Education

The past decade has seen a growing chorus of concern about the state of science and mathematics education in schools in North America. The studies described in Part A of this report are only a selection of those that have appeared most recently. This wave of interest and concern dates back to the mid 1970s when the National Science Foundation commissioned a series of major reviews of the state of science education in the United States.

They were based *at that time* less on a sense of impending economic threat as on a desire to determine the impact of the major funding that the NSF had injected into science curriculum development during the 60s. As Jim Rutherford, then Assistant Director of the NSF for Science Education expressed it:

> But what was the lasting outcome (of the NSF-led efforts of the 60s to improve science education)? After 20 years of trying to improve instruction in mathematics and in the natural and social sciences, what is the situation today? This question . . . is of interest to the Foundation, to the National Science Board, to Congress, to all of the thousands of teachers and scientists who participated in the reform effort in one way or another, and to education policymakers. It is a question that deserves an answer.[32]

The NSF's studies provided the somewhat disappointing answer that science education had changed remarkably little as a result of the massive intervention and that many of the problems that had motivated the NSF reform efforts were still there. The studies also raised questions about the numbers of young people who had become disenchanted with science in school and who were no longer taking science (thus limiting the numbers of future scientists and engineers).

These concerns were compounded when the Educational Testing Service began systematic national assessments of science education achievement. These efforts culminated in the international studies in mathematics and science reviewed in the present report, which revealed that those students who were taking science were performing less well than their counterparts in other countries.

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[32] F. James Rutherford, foreword to *The Status of Pre-College Science, Mathematics and Social Studies Educational Practices in U.S. Schools* (Washington: National Science Foundation, 1978).

In former times, these findings would have been cause for yet further concern. Now, however, they are the basis for action. This is a reflection of the fact that American (and Canadian) industrialists have just become aware of the global nature of the markets in which they must compete and of the competitive importance of the education and training of their personnel.

In Canada, the concerns had a somewhat different origin and were more varied in their nature. There have not been any public systems of achievement testing until relatively recently and even now they only exist in some provinces. There is no national presence or infrastructure (either federal government or non-governmental organization) in science education. The Science Council of Canada's study and the provinces' participation in the international achievement studies were a major step forward in this regard. They have confirmed, however, that, while the science and mathematics education scene in Canada is less discouraging than that in the United States, it is only with that country that comparisons are comforting.

During the last five years, in the United States and to a much lesser degree in Canada, attention has been turning from analyzing the evidence and discussing the nature of "the problem" to trying to find solutions and instituting programs of renewal. Many of the studies referred to earlier contain recommendations for the reform and renewal of science and mathematics education and it is to these initiatives that this report now turns its attention.

As with the studies in Part A, these initiative may be categorized on the basis of their geographical scope:

- U.S. national initiatives;
- U.S. state initiatives;
- Canadian national initiatives;
- Canadian provincial initiatives.

Each of these four areas are now reviewed briefly.

■ U.S. National Initiatives

1 U.S. Federal Government

Despite a constitutional allocation of education to state jurisdiction not unlike that of Canada, the federal government of the United States has, for many years, instituted educational policies and programs in support of certain national objectives. These have included, over the past three decades especially, programs of support for science and mathematics education at the elementary and secondary school levels. Current levels of federal spending on such programs amount to about $260 million (U.S.) or $1 for every man, woman, and child in the nation. These support programs are divided between the National Science Foundation, which is currently spending about $120 million on pre-college science and mathematics education, and the Department of Education,[33] which provides block grants totalling $137.7 million to school districts for special initiatives in science and mathematics education.[34] For the 1990 fiscal year, the National Science Foundation has requested significant increases to its allocation for science and engineering education.[35] Other federal departments and agencies (such as the Department of Energy and NASA) have programs affecting science and mathematics education to a lesser extent.

In addition to these major government programs, many other organizations are active in supporting improvements in science and mathematics education. A complete inventory is beyond the scope of this paper. However, the following special organizations and initiatives should be noted.

2 The Triangle Coalition for Science and Technology Education

This organization represents a new direction in science education in the United States because it is made up of three sectors – scientists, industrialists and educators – working together to ensure the improvement of science and mathematics education. It does so by working at two levels simultaneously.

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33 This program is known as the Education for Economic Security Act (EESA), Title II (Mathematics and Science Education).

34 Coalition for Education in the Sciences (AAAS), *Science Education News*, Volume 6, number 7 (September 1988).

35 Coalition for Education in the Sciences (AAAS), *Science Education News*, Volume 7, number 2 (February 1989).

At the national level, the Coalition comprises an alliance of over 70 institutional members, including scientific associations (such as the American Chemical Society, the American Institute of Physics and so on), business, industry and labour (such as Apple Computer, Dupont, United Auto Workers) and Education (the Council for Basic Education, the National Science Teachers' Association and the Council of State Science Supervisors). This represents a formidable group of organizations dedicated to collaboration in support of science and technology education. On the national level, it has set up a number of task forces to review and make recommendations concerning identified problem areas, such as elementary science education and educational technology.

At the local level, the Triangle Coalition encourages the formation of school-industry alliances, especially but not exclusively in the science and technology area. Supported by a Carnegie Corporation grant, the Coalition is providing networking amongst many of these groups around the country. This networking function helps new groups learn from the experience of old groups about projects that have a high chance of success. The Coalition also provides a database of teacher assistance programs and provides "mini-grants" to groups wanting to establish local science-based partnerships.

3 The American Association for the Advancement of Science

The AAAS Office of Science and Technology Education has a range of special programs in operation, the most prominent of which are Project 2061 and the National Forum in School Science;

Project 2061, whose first reports have just been released,[36] is a major initiative designed to last about 10 years, whose goal is to reformulate the objectives and strategies of education in science, mathematics and technology for life in the 21st century. The name 2061 reflects the fact that Halley's comet was close to the earth in 1985 when the project began and that that year is its next anticipated return. The first set of reports are a response to the question: "what should be taught to students who will grow up in the 21st century?". These deal with the substance of scientific literacy and a broad range of distinguished scientists and others have contributed to the response. Phase 2 addresses questions of teaching and learning in the light of the conclusions of phase 1, and phase 3 will be focused on the problems of implementing change in the schools.

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36 American Association for the Advancement of Science, *Science for All Americans*, report of phase 1 of Project 2061 (Washington: AAAS, 1989).

The second major project in which the American Association for the Advancement of science is involved is the National Forum on School Science, an annual conference addressing in turn the problems of the science curriculum, science teaching and science learning. This program is intended to draw in policymakers and educators from around the nation to debate policy questions in each of these three areas and its reports have been published for each of the first four years that the forum has operated.

4 The National Research Council of the National Academy of Sciences

One of the weaknesses of science and mathematics education in Canada has often been the absence of information by which the quality of this education could be determined. While students' achievement in science is important, the effects of many factors on that variable also need to be taken into account, as has been noted earlier. Given the importance, however, of indicators of Science and Mathematics education, the National research Council of the National Academy of Sciences undertook a major study of this matter and its reports are useful.[37] This project recommended that the following key indicators be adopted:

- *Extent of student learning in mathematics and science;*
- *Extent of scientific and mathematical literacy of adults;*
- *Enrolment data for mathematics and science courses taken by students in high school and the amounts of time spent on the study of science and mathematics in elementary and middle/ junior high school;*
- *Nature of student activities during science and mathematics instruction;*
- *Extent of teachers' knowledge in the subject matter that they are expected to teach;*
- *Salaries paid to college graduates with particular subject-matter specialties who choose to enter various occupations;*
- *Quality of the curriculum content in state guidelines, textbooks and associated materials, tests, and actual classroom instruction in science and mathematics through matching to exemplary curriculum*

[37] Committee on Indicators of Precollege Science and Mathematics Education, *Indicators of Precollege Education in Science and Mathematics: A Preliminary Review* (1985) and *Improving Indicators of the Quality of Science and Mathematics Education in Grades K-12* (Washington: National Research Council of the Academy of Sciences).

> *frameworks along four dimensions: breadth and depth of treatment and scientific and pedagogic soundness.*[38]

The report goes on to propose that data be collected on each of these indicators every four years and analyzed in a variety of ways according to geographical, racial, gender-related and other variables.[39]

A second project that the National Academy of Sciences is currently undertaking (on behalf of the Howard Hughes Medical Institute) is on the future of high school biology. This project is still in its early stages and no reports have been forthcoming as of the time of writing. The Howard Hughes Medical Institute has expressed concern over the number of prospective researchers in the medical science in the United States in the coming decades and one can assume, therefore, that this will be a major focus of this project.

[38] *Improving Indicators of the Quality ...*, *op. cit.*, pp.2-3.

[39] This project should also be contrasted with a study of indicators actually in current use by state departments of education, described later (under U.S. state initiatives).

• U.S. State Initiatives

At the state level, legislators have been concerned enough by the reports on the apparently weakening state of science and mathematics education in American schools that they have been undertaking a variety of initiatives.

1 The Council of Chief State School Officers

This organization, which is approximately equivalent to the Council of Ministers of Education, Canada, has undertaken a State Science and Mathematics Indicators Project, which has included a state-by-state inventory of indicators on Science and Mathematics. A summary of its work is appended.

> *Many states have instituted reforms that are aimed at improving science and mathematics education in elementary and secondary schools. Standards for teacher certification have been raised, curricula have been revised, course requirements for graduation have been increased, and incentives have been provided for attracting and retaining teachers in science and mathematics. The Council of Chief State School Officers is providing leadership in improving states' capacity for assessing the effects of the reforms through a three-year project to develop and improve state-level indicators and data on science and mathematics education. The project, which began in September, 1986, is supported by the National Science Foundation.*
>
> *There are two major goals for the project: 1) to improve the quality and usefulness of data on science and mathematics education to assist state policy-makers and program managers in making more informed decisions, and 2) to develop a system of indicators that provides the capacity for state-to-state comparisons of science and mathematics education as well as a national database to assess the condition of education in these subjects.*
>
> ***Results of Year One.*** *In the project's first year, states reported on their current policies, indicators, and data related to science and mathematics education. A survey was conducted through a 50-state network of curriculum, assessment, and information systems specialists. The survey was based on a framework of "ideal indicators" drawn from recent studies by the National Academy of Sciences, The Rand Corporation, and CCSSO's plan for education indicators. Some of the findings of the survey were that:*
>
> - *More than forty states have programs of student achievement testing in science or mathematics;*
> - *Thirty-four states collect secondary student enrolment by course, most often through teacher assignment information;*

- Twenty-five states provide direction or guidance on elementary class time to be spent on science and mathematics;

- Thirty-one states develop estimates of teacher shortages or supply and demand.

In contrast, only seven states collect information on student attitudes/intentions toward further education in science/ mathematics, and fewer than ten states collect data on minutes per week actually spent on elementary science and mathematics.

Results of Year Two. In its second year (beginning September, 1987), the project has been concerned with planning and implementation of a set of priority state indicators of science and mathematics education. The priority indicators were identified through several steps. A task force comprised of state science and mathematics specialists, state data managers, and experts on educational indicators analysed the results of the inventory against the ideal indicators.

Three criteria were applied in reviewing potential science/math indicators: a) importance/usefulness of the indicator at state, local, and national levels, b) technical quality of the data, and c) feasibility of obtaining state-by-state data. Based on the task force's recommendations, a list of priority indicators was submitted to the chief state school officers, and they were approved in November, 1987.

Three priority indicators are being developed from data collected through state data systems: (a) secondary course enrolment in science and mathematics, (b) teacher assignments by subject/field, and (c) assignments by certification status. Other indicators would be obtained through national surveys that include state samples, such as the National Assessment of Educational Progress (starting 1990) and the Schools and Staffing Survey (1988), both conducted by the National Center for Education Statistics.

Since January 1988, the project has been working with representatives of the states, in groups and individually, to implement a state-by-state plan for reporting comparable data on the priority indicators based on state data. Five regional meetings were held to discuss the indicators plan and to exchange ideas and strategies about the development and use of science/math indicators; the meetings were attended by 110 state education professionals. A pilot study is being conducted with 10 states to test the plan in preparation for beginning the state indicators reporting in 1988-89. Each chief state school officer has been notified of the status of his/her department on the three indicators, and each chief has been given several options for reporting the data and/or receiving technical assistance over the next year.

Plans for Years Three and Four. CCSSO has submitted a continuation proposal to NSF for two years of support. In the third year (beginning September 1988), the project will coordinate the phase-in of state reporting on three priority indicators and assist other states in developing their state data capacity. The project will also obtain state

representative data on other science/math indicators from national surveys. Finally, the project will be working with small groups of states on developing additional indicators, including teacher supply/ demand, elementary instruction, and assessment in science and math.

In the fourth year (beginning September 1989) the project will coordinate the full implementation of data reporting on priority science/math indicators and will work with all the states in collecting, editing, tabulating, and analysing state data on science and mathematics. The project will be planning with the National Science Foundation and the National Center for Education Statistics to implement a system of periodic state-by-state reporting for the science/math indicators.

Three project reports are available at this time: 1) State Education Indicators on Science & Math, Results of a 50 State Inventory; 2) State Policies Related to Science & Mathematics Education; and 3) Indicators of Science & Mathematics Education: Providing Tools for State Policymakers.[40]

2 The Education Commission of the States

This organization, which has no direct parallel in Canada but which is a policy research and analysis institute funded by but at arm's length from the states, has recently completed an inventory of State initiatives to improve science and mathematics education and the highlights of this report are reproduced below.

HIGHLIGHTS AND OVERVIEW OF STATE SCIENCE AND MATHEMATICS INITIATIVES

States have been very active in the areas of curriculum development, teacher training, recruitment and certification, and student assessment. An overview of state initiatives in these policy areas is presented below; highlights of policies and programs are included to provide information on the range of initiatives.

Curriculum Guides

Curriculum guides for science and mathematics in the 50 states range from very general recommendations to minimum standards that are

[40] Each report can be obtained for $2.00 per copy, pre-paid, from Rolf Blank, Director, Science/Math. Indicators Project, Council of Chief State School Officers, 400 N. Capitol Street, N.W., Washington, D.C. 20001.

required for district use. For example, the Mississippi State Curriculum Structure defines and mandates course titles, course descriptions and minimum learning objectives for use in local Instructional Management Programs. Other states have curriculum development guides that may include learner outcomes and are recommended for district use. Connecticut's common Core of Learning does not define minimum competencies; rather it suggests "... an integrated and interdependent set of learner outcomes... expected to result from the entire K-12 school experience." A few states, like California, have very comprehensive, recommended guides that integrate curriculum development, textbook adoption and long-term staff development planning.

Forty-seven states have some form of curriculum guide for science or mathematics; three states, Montana, Nebraska and Wyoming, do not have any form of curriculum guides for any subject area. Twenty-nine of the states have recommended science curriculum guides and 20 have required science guides. Twenty-seven of the states have recommended mathematics curriculum guides and 20 have required mathematics guides. It is important to note that some states have both recommended and required curriculum guides. For example, South Carolina has a recommended Outline of High School Credit Courses and required Basic Skills Objectives for grades K-12. Utah has recommended curriculum guides for grades K-6 and 9-12 and required specific CORE courses for grades 7 and 8.

Higher Order Thinking Skills

Higher order thinking skills top the agenda of many educational policy makers, and most states report activity in this area. Some states incorporate higher order thinking skills through staff development. For example, Iowa and Maine sponsor annual conferences through Title II funds for science and mathematics teachers to promote Problem Solving in Science and Mathematics (PRISMS). In the state of Virginia, inservice workshops have been held on a statewide basis that emphasize higher order thinking skills. Virginia is also developing a series of television programs aired beginning September 1987, that emphasize higher order thinking skills. Other states include these skills in their assessment programs. Missouri reports that when the Missouri Mastery and Achievement Test (MMAT) items were developed, the writers were instructed to design test items that would assess higher order thinking skills. There has been a review by cognitive psychologists indicating that a "... good portion of the MMAT is assessing higher level thinking."

Still other states report that higher order thinking skills underlie and are the basis for their curriculum guides. For example, the Texas Essential Elements for Science, a curriculum framework, is process oriented, and the Essential Elements for Mathematics emphasizes problem solving. The state of Maryland awards curriculum development and implementation grants to districts that emphasize higher order thinking skills. In Minnesota, grants from Cray Research, Inc. and the Minnesota High Technology Council are being used by the Department of Education to

define higher order thinking skills and to implement curriculum models that emphasize these skills.

Even though states report general activity in the area of higher order thinking skills, caution must be exercised when analyzing the real effect of that activity. It is questionable whether including such language as "identify," "distinguish" and "demonstrate" in curriculum guides will change the way students think unless concrete activities take place that back up this language. For example, the best way to learn about community affairs is to get involved in them. Providing concrete activities that actually do require students to "identify", "distinguish" and "demonstrate" will automatically develop higher order thinking skills.

Graduation Requirements

In many states, minimum state graduation requirements for science and mathematics have existed for several years; in a few other states, requirements have recently been introduced for the first time. However, many states with long-standing graduation requirements have made changes (mainly increases) during the past few years. According to the survey data, 46 states as well as American Samoa have either introduced or changed state minimum high school graduation requirements for science and/or mathematics since 1974. Only four cities, Colorado, Iowa, Massachusetts and Wyoming, do not have state-level graduation requirements. (Colorado has a constitutional prohibition against state high school graduation requirements.)

Some state-level requirements are mandated for use by school districts; others are recommended rather than required for use. Even when state graduation requirements are recommended for use, there is often some pressure for districts to adopt the requirements. For example, Michigan recommends that districts adopt the state-established graduation requirements and offers incentives to districts that do so. Among the states that have minimum graduation requirements, five require only one science credit for graduation, 36 require two credits and six require three credits. State minimum graduation requirements for mathematics tend to be higher. Only one state requires one mathematics credit for graduation, 35 of the states require two credits, nine require three credits and only one state requires four credits.

Some states test for basic skills in certain subject areas for high school graduation. While 15 states require an exit-level exam in mathematics, only five states require an exit-level exam in science. Interestingly, every state that requires a science exit exam also requires one for mathematics. the five states that test both science and mathematics knowledge for high school graduation are Florida, Idaho, Illinois, Louisiana and New Mexico. (Note: Louisiana's science exit exam will begin in 1989.)

All of the above requirements apply to standard diplomas; however, several states now offer advanced or honors diplomas that require additional course work or demonstration of competency. For example,

requirements for the Indiana Academic Honors diploma include six credits of science and six credits of mathematics. Kentucky students may earn the Commonwealth Diploma by completing three credits of science and four credits of mathematics. In Idaho, a Seal of Proficiency is added to standard diplomas if students pass all four subtests of the Idaho Proficiency Test. In Texas, an advanced notation is placed on transcripts if students complete three years each of science and mathematics and one year of computer science. Missouri's college Preparatory Studies Certificate Program offers incentives to college-bound students or students who simply wish to follow a more rigorous course of study. However, completion of this program does not lead to an advanced diploma but instead to a certificate that signifies outstanding academic achievement. Requirements for this certificate include completion of three units of science and three units of mathematics, a minimum GPA of 3.0 on a 4.0 scale in the combined areas of English/language arts, mathematics, science and social studies as calculated at the end of either the seventh or eighth semester of high school, and scores on the ACT and SAT above the national averages.

Often state graduation requirements are overshadowed by college admission standards. For example, in North Carolina, college-bound students must complete three units of science and three units of mathematics to meet college entrance requirements, which exceed the state minimum graduation requirements of two credits each. In this case, the college entrance requirements have become the de facto high school graduation requirements for college-bound students (beginning with the class of 1988).

Recognition and Awards for Students

Survey respondents were asked to identify state-supported (state-funded) recognition programs for students in science and mathematics. Strictly state-supported programs are rare. The ones that do exist usually follow a common state fair or knowledge-bowl format. For example, the ARkansas Governor's Academy Competition, more commonly known as the Arkansas Quiz Bowl, is a quick recall test of general-knowledge facts in a variety of subject areas, including science and mathematics.

Teams of four from public high schools in the state enter regional competitions; regional winners advance to the state-level competition where prizes include trophies, $1,000 college scholarships and a chance to compete at the national level. Some exemplary state-supported recognition programs were identified and deserve mention.

In 1983, California's Hughes-Hart Educational Reform established the Golden State Examination (GSE) to identify and recognize honors-level achievement by students in specific academic subject areas. Any student enrolled in a subject to be tested may take the GSE. The GSE, first administered in May 1987, covered first-year algebra and geometry. Future tests, planned for the spring of each year, will cover additional mathematics courses, laboratory sciences, U.S. history,

English literature and composition, foreign languages and health science. Students are recognized at one of three levels based on state-wide standards: high honors, honors and school recognition. Students who achieve high honors or honors receive a certificate acknowledging their outstanding achievement plus an insignia on their high school diploma and a notation on their transcript. Students who achieve school recognition status do not receive certificates from the state but may receive some form of recognition from their schools.

PRIDE, a Program to Recognize Initiative and Distinction in Education, is sponsored by Florida's Commissioner of Education. It identifies outstanding students in the areas of science and mathematics through a series of school, district, regional and state competitions. Top winners receive awards and scholarships to state colleges and universities.

There are multitudes of recognition and award programs at the state level that are privately supported by professional organizations or business industry, or jointly supported through several resources, including the state. These types of programs often begin at the local or regional level and end at the national level. Programs like those identified below are common to most states.

The Junior Academy of Science, for students in grades 7-12, is sponsored by each state's Academy of Science. Science Olympiads, for grades 8-12, are sponsored by state affiliates of the National Association of Teachers of Science. Junior Science, Engineering and Humanities Symposiums, for grades 9-12, are sponsored by private industry, states and the United States Army.

MathCounts, sponsored mainly by the Society for Professional Engineers, is another popular recognition program in which most states participate. Seventh and 8th grade students form teams and enter regional competitions; the top three teams from each region then enter a state competition. MathCounts culminates in Washington, D.C. with the top team from each state competing for the number-one spot.

Other noteworthy recognition programs include the New York Energy Research and Design Competition, sponsored by the New York State Energy Research and Development Authority; High Flight, an aerospace workshop sponsored by the Oklahoma Aeronautics Commission; the SHARP Program, and eight-week program that allows students to work with Goddard Space Center scientists and earn minimum wages; Science Congress, a research-based competition for high school seniors, sponsored by the Wisconsin Society of Science Teachers and the Wisconsin Academy of Science; and an Invention Convention, for students in grades K-12, sponsored by the Oklahoma Department of Education and the Oklahoma Department of Commerce.

Beyond state-supported and state-level recognition programs, several national programs exist to recognize outstanding achievement in science and mathematics. These include the West Virginia National Youth Science Camp, U.S. Department of Energy Institutes, the Westinghouse Science Talent Search, the National High School Mathematics Examina-

tion and the National Junior High School Mathematics Examination. Dominos Pizza also sponsors an national Domino's Competition.

Special Schools

Only a handful of states solely support magnet or residential schools that provide specialized subject area study. Like recognition programs, special schools are more often supported through private organizations or through a combination of resources. Fifteen states report sponsoring, at least in part, schools that focus on science; two more states report that they are considering or proposing a special, science-oriented school. Twelve states report having special schools that focus on mathematics; one state is currently proposing such a school while yet another is developing one. some states report having more than one special school and are mentioned below.

The state of Pennsylvania has a variety of special schools in a variety of subject areas, including science and mathematics. The Pennsylvania Governor's School for the Sciences, established at Carnegie-Mellon University with state and foundation monies, accommodates more than 90 students per year. Selection is competitive, based on SAT score, GPA, class rank, teacher and counselor ratings and recommendations, and number and level of science and mathematics courses completed. The Pennsylvania Governor's School for Agriculture, located at Pennsylvania State University, focuses primarily on the sciences and technology in an effort to "shed its plow and cows image." Selection criteria are similar to those above. Some of the other states that report special schools include North Carolina, Louisiana and Virginia. The North Carolina School of Science and Mathematics is a residential school located in Durham, North Carolina. It provides students who have recognized aptitudes in science and mathematics with an advanced educational program and enriching atmosphere. The Louisiana School for Science, Mathematics and the Arts, established in 1983, is located in Natichitoches, Louisiana at Northwestern State University and is patterned after the North Carolina School for Science and Mathematics. Louisiana's school accommodates 700 talented high school juniors and seniors who are nominated by their school districts. In Virginia, state and local monies support four magnet schools in science: the New Horizon Magnet School for Science, the Roanoke Governor's School for Science and Mathematics, the Thomas Jefferson High School for Science and Technology. Also supported by Virginia are six Summer Governor's Schools for Science and Technology. Approximately 3,000 students participate in these programs annually.

Summer Programs

Summer programs that provide additional opportunities to students to enhance their education are more popular among states than special schools (possibly because summer programs have a shorter duration and therefore cost less to operate). Summer institutes and special programs are offered in 20 states to students studying science; 19 states provide

summer mathematics programs. Generally, summer programs last from one to six weeks and focus on a variety of subjects. For example, the state of Wisconsin sponsors Science World, a one-week, integrated physical science/biology/earth science program located at Pigeon Lake. Not only does this program provide exciting educational experiences for students, it also provides professional development experiences for teachers.

Six hundred students in North Carolina participate in Summer Ventures during the summer of 1987. Summer Venture programs, located at five different North Carolina university campuses, are five-week long residential workshops. Specific course offerings vary by program location, but the overall curriculum focuses on science, mathematics and the use of computers.

Some states do not host summer programs at all but rather participate in programs in other states. For example, American Samoa does not support its own summer programs, but its students are not denied the opportunity to receive additional training during the summer. Five to six students are selected from American Samoa by the University of Hawaii each year to participate in a six-week summer program that focuses on marine biology, oceanography, navigation and ecology.

Some states appropriate a relatively large amount of money for special summer programs. For example, Florida's state education agency received $1,213,465 in 1986-87 for summer programs. This appropriation is in accordance with recent Florida state legislation that allows the state education agency to award grants to public school districts, higher education institutions, museums and any educationally oriented, nonprofit organization to conduct summer camps for students in science, mathematics or computers.

Special Populations

More than one-half of the states report programs designed to increase the participation of special populations in science and mathematics; 29 states report programs that focus on science and 33 report programs that focus on mathematics. Several of these programs aim to introduce women and minorities to career options based on science and mathematics. Programs of special interest include the Oregon Multi-Cultural Science Association, a program being organized by the state and the Native American Science Education Association with Chapter 1 monies. Multicultural studies in science and mathematics will be promoted. For example, biology will be taught from a Native American perspective.

Montana also emphasizes Native American issues in education. The Native American Olympiad is held annually. Students of Native American descent are encouraged to participate in this science-and computer-focused program.

In Colorado, participation of minority groups in science is stimulated through MESA (Minority Engineers and Scientist Association). Minority

students in grades 7-12 are encouraged to develop strong backgrounds in science and mathematics and to pursue careers in technical areas.

The state of Nevada promotes equity in education through "Odds on You' mathematics workshops. During these sessions, young women are encouraged to enroll in advanced mathematics classes and to pursue mathematics-related careers.

In 1986, Georgia's Department of Education and Board of Regents conducted 14 Futurescape seminars at colleges and universities throughout the state. These seminars allowed young women at the high school level to meet professional women whose careers are dependent on an educational foundation in science and mathematics. Funding at the state level terminated after 1986, however, some colleges continue to fund and conduct Futurescape seminars.

Wisconsin's Science World, noted in the previous section on summer programs, does more than link student learning with teacher training. During the selection process, priority is given to minority and handicapped students. Furthermore, 50% of its participants are women.

Some programs that serve special populations are reported by more than one state. "Expanding Your Horizons in Science and Math" are conferences held in Colorado and Montana. During Horizon conferences, young women are made more aware of career opportunities in technical fields, such as engineering and computer science. The EQUALS program, reported by North Carolina and New Hampshire, also focuses on women, particularly in the area of mathematics.

In addition to women and minorities, special populations include gifted and talented students. Too often the needs of these students are overlooked, resulting in their loss of interest in school and possibly dropping out of school. Colorado's reform effort, the 2+2 Project, plans as part of its initiatives to improve educational opportunities for gifted and talented students. More specifically, 2+2 plans to offer a "... renewed commitment to building science experiences that ensure gifted and talented students are intellectually nourished."

The state of Mississippi also plans to enhance the education of gifted and talented students. The legislature recently approved the establishment of a special boarding school for gifted high school juniors and seniors that will focus on science and mathematics. The school is scheduled to open for the 1988-89 school year.

Student Assessment

States have responded to the public pressure for accountability. Forty-six of the states (including American Samoa) have a statewide testing program. Of this 46, 30 assess science knowledge and 43 assess mathematics knowledge. Only five states (Alaska, Montana, Nebraska, Ohio and Vermont) delegate educational accountability responsibilities

to school districts or schools themselves. This is an adjustment recently made by Alaska and Montana.

Teacher Shortages

Two types of teacher shortages were reported in the states: a shortage of teachers and a shortage of qualified teachers (teachers whose subject matter background is insufficient). In science, 17 states report a shortage of qualified teachers while 20 report a shortage of teachers in terms of quantity. Six of these states, Arkansas, Iowa, Pennsylvania, Texas, Virginia and West Virginia, report teacher shortages specifically in the areas of physics, chemistry or earth science or some combination of the three. In mathematics, 14 states report a shortage of qualified teachers while 25 report a shortage of teachers in terms of quantity. Several respondents qualified their answers by adding that teacher shortages weren't statewide but confined to small, rural districts.

Conversely, New York reports that its teacher shortages occurred primarily in large, urban districts. Pennsylvania is the only state that reports an shortage of qualified substitute teachers in mathematics.

Most states, aware of teacher shortages,have made some attempts to alleviate them. For example, Connecticut combats teacher shortages with higher teacher salaries, a loan program available to physics and mathematics teachers and continued staff development.

Iowa has an extensive array of programs designed to reduce and prevent teacher shortages. Examples include the Iowa Science and Math Loan Program, designed to assist current teachers to obtain or upgrade their teaching authorization in science or mathematics. The state may grant loans for up to $1,500 if students are enrolled at least part-time in an appropriate course of study. Loan recipients receive full loan cancellation benefits if they teach science or mathematics in an approved Iowa School for at least two years.

Profits from Iowa's lottery provide teachers with tuition, materials, room and board and a $150 per week stipend if they participate in the Iowa Lottery Funds to Revitalize Current Mathematics and Science Teachers summer program. Four summer institutes are held during the summer of 1987 and four more are being planned for the coming year.

Mississippi is using a very familiar means to cope with teacher shortages - the television. A pilot plan is under way that delivers science instruction via satellite to classrooms that lack teachers.

Teacher Recruitment

As was indicated above, classroom teachers are becoming a scarce commodity, especially in science and mathematics, due to higher salaries and better working conditions in the private sector, retirement and natural attrition. In Florida alone, it is predicted that one-third of

the mathematics teaching force will retire in the next five years. Recruitment efforts must gear up to avoid these predicted teacher shortages.

Current recruitment strategies vary from state to state. However, the most common strategy, as identified by survey respondents, is a forgivable loan program. Twenty-five states report a loan program for persons who receive teacher training in science or mathematics. Loan programs are either for undergraduates who become certified for the first time or current teachers who become recertified. The Iowa Science and Mathematics Loan Program, described in the previous section, is a classic example.

Closely related to loan programs are scholarship programs. Seven states report scholarship programs for potential science teachers and six report scholarship programs for potential science teachers and six report scholarship programs for potential mathematics teachers. For example, Idaho uses Title II monies to provide scholarships to potential science or mathematics teachers or teachers who want to become recertified in one to these subject areas. Similarly, American Samoa's Department of Education offers scholarships to science majors who enter the teaching profession.

Another typical recruitment strategy is alternative certification. (For the purposes of this survey, alternative certification means full certification despite a lack of traditional credentials.) Only 12 states offer an alternate route to certification in science and only 10 offer an alternate route in mathematics. In Maine, certification may be granted to qualified persons following a transcript analysis and completion of only six semester hours of educational course work. (Depending on the transcript analysis results, additional course work could be prescribed.) In Utah, Eminence Certificates are available to professionals such as doctors and engineers. An Eminence Certificate allows them to teach up to two class periods per day. Some states do not provide an alternate certification program but allow districts to do so. For example, the state of Texas allows its districts to develop their own alternate certification programs given a documented or projected need.

These three types of recruitment strategies – loans, scholarships and alternative certification – are often effective but rather basic.

Several states have developed more innovative ways to recruit people into the teaching profession.

By dialing 1-800-FL-TEACH (an in-state number) or 1-800-TEACH-FL (an out-of-state number) interested people can receive teacher recruitment referrals for the state of Florida. In addition, the Great Florida Teach-In occurs each June to help teachers find jobs in Florida. This program has a relatively high success rate; of the 1,500 teachers who attended the 1986 teach-in, over half were offered teaching positions.

California and Georgia participate in a novel recruitment program that simultaneously promotes cultural exchange. Both states actively recruit science and mathematics teachers from West Germany.

Another teacher recruitment and public awareness campaign in California is headed by Bill Honig, Superintendent of Public Instruction, and Ann Reynolds, the head of the California State University system. During visits to universities with teacher preparation programs, Superintendent Honig encourages students to "Be a Class Act: Be a Teacher" and explains the rewards of teaching and provides general information about the profession.

Teacher Training and Retention

After states successfully recruit people into the teaching profession, the next task is to keep them there. With fierce competition form the private sector, this task is often very challenging. Twenty-six states report having some type of teacher training or retention program for science and mathematics teachers. Approximately half of these programs involve loans and scholarships to promote additional course work (similar to those used to recruit teachers.) The other half is divided among a variety of programs. Examples include the Teacher Summer Business Training and Employment Program in New York that provides a portion of salary reimbursement for science, mathematics, computer or occupational education teachers employed by business and industry during the summer months.

In Kentucky, Title II funds support the Science Improvement Project (SIP) for physical science teachers at the secondary level. The state has hired an outstanding physics teacher to serve as a consultant to schools within the 5th and 7th Congressional districts. (These districts were chosen due to low income levels and low achievement scores.) The consultant will show physics teachers in these districts how to teach science more effectively, how to use mathematics in teaching science and how to integrate computers into science instruction.

Staff Development Needs

Perceived weaknesses in teaching skills among science teachers fall into three main categories: content, methodology, and curriculum. More specifically, within the area of science content, elementary teachers were identified as needing the most staff development, especially with experiments and working with hands-on materials. Middle school teachers need general content training. Likewise, cross-over teachers at the high school level, or those who teach science but are officially certified in another subject area, need general content training. High school teachers who are officially certified in science need the content training necessary to teach lower level science, chemistry, physics and earth science.

Within the category of methodology, all science teachers need training in the use of hands-on instructional approaches, manipulatives, higher order thinking skills, problem solving and small group projects. Several states are concerned that "particularly elementary teachers (lack and need) experience with inquiry and activity-oriented teaching."

Identified staff development needs in terms of science curriculum issues include curriculum development, establishment of goals, coordination of the curriculum and assessment tools, curriculum coordination between grades K-12 and integration of science with other subjects. One respondent remarked, "It is crucial that teachers teach from an integrated approach in terms of both grade level and different subject areas."

Identified staff development needs among mathematics teachers also fall into three categories: content, methodology and currency. All mathematics teachers need staff development in higher order thinking skills, problem solving, inquiry skills and estimation. Elementary teachers especially need training in problem solving and higher order thinking skills.

Staff development needs in terms of methodology include problem solving, integration, use of manipulatives, applications, serving students' needs and small group projects. Elementary teachers especially need training in manipulatives and hands-on experiences; high school teachers need training in consumer applications. The use of technology in teaching mathematics is a special methodology issue expressed by several states as a staff development need.

Currency issues, or bringing mathematics teachers "up-to-date," is another identified staff development need. Teachers at all levels need to learn of current research, content and teaching techniques. Mathematics teachers also need to be updated in terms of higher order thinking skills, statistics and probabilities, manipulatives and applications.

Trends and Issues

Survey respondents were asked to identify major problems that their states face in improving science and mathematics instruction; many of their answers echo those included in the previous section on staff development needs.

Trends, problems and concerns about science mainly evolve around teachers' issues, school-wide issues and funding issues. The majority of concerns have to do with teachers and teaching. Ten states voice a concern for improving science content especially in the areas of physical science and lower level science. "Providing guidance to teachers of 'slower class'" is especially difficult. Thirty states note concern for methodology among science teachers; half of these states stressed concern with methodology at the elementary level followed by emphasized concern at the middle school level. Given this information, it may be that teachers know how to teach the subject of science but they do not know how to teach science to young children. Evidence of this comes

from several states, including California, Connecticut, Louisiana, Michigan, Montana, New York, South Dakota and Vermont. Montana recently conducted a statewide needs assessment in science, mathematics and computer education. One of the identified needs is that "elementary teachers need to more fully understand the use of hands-on, inquiry and activity approaches in teaching science." One respondent in New York commented that "science programs at the middle/junior high school level lack concrete, "hands-on" activities related to the real world."

Many other teachers issues were cited. Fifteen states expressed a real concern abut negative teacher attitudes toward science; they need to understand "... the real mission of science which is teaching science as a creative, inventive endeavor." This is particulary true among elementary teachers who combine this apathetic attitude with anxiety toward teaching science. One respondent commented that if elementary teachers had "... more content knowledge in areas of science, (this would help) to overcome the anxiety they fee." Another respondent feels that "... instilling confidence in elementary teachers [will] make teaching science less stressful." However, one respondent said it best; "If [society] had as much interest in science as [it does] in athletics, the science program would be pretty well off."

Another identified concern reported by several states is one of teacher shortages. As was noted earlier in this summary, 37 of the states report a shortage of science teachers in terms of either quality or quantity. This is a serious situation since only six states noted a concern about ongoing training to upgrade the quality of current teachers and only three states voiced any concern about recruiting new persons to teach science. Other teacher issues identified by respondents include textbook dependency, cross-over teaching and lack of adequate preservice preparation.

Beyond concerns about teaching and teachers were school-wide issues. Large class size topped the list, followed by lack of time for science, laboratory safety, special needs of students and equity. One state legislative has addressed the lab safety issue by passing a "Right to Know" law that is prefaced on the right of the public to know about the hazards of chemicals with which students and teachers may come in contact. According to one respondent, "The intent of the legislation is good... but there is a lot of red tape and paperwork involved that takes time away from instruction."

Lack of funding was reported by 39 of the states as a major issue. Half of those states specifically cited lack of funding for materials and updating laboratories as a major problem. Lack of funding for staff development and teacher salaries was also specified as crucial.

Problems and concerns relating to mathematics instruction can also be classified in terms of teachers issues, school-wide issues and funding issues. As with science problems, the majority of concerns have to do with teachers. Twelve states express concern that "... mathematics teachers lack adequate content knowledge ... particularly in the areas of low ability and remedial instruction." Sixteen states report problems in

terms of teaching methods. One respondent state that "mathematics teachers lack the necessary skills to deliver quality mathematics instruction especially where computers and other technologies are concerned." Another respondent added that "mathematics teachers need to learn alternative strategies for teaching mathematics; it can be made exciting and dynamic."

Teacher attitudes toward mathematics, again like science, are dangerously negative. Eleven states expressed concern that there needs to be a clearer understanding of the total scope of mathematics. Teachers just "don't have a clear understanding of what mathematics is ... and apparently don't care." For example, in Pennsylvania, only 5-10% of the teaching population attends statewide mathematics workshops on a regular basis. Not surprisingly, several states report problems in terms of participation in staff development.

School-wide issues related to mathematics are again similar to those related to science. Inequity and lack of time for planning are reported by a few states as barriers to improving mathematics instruction. In terms of inequity, one respondent stated, "We cannot continue to ignore the needs of historically underrepresented and underserved groups... their needs must be met." Several funding issues are reported that relate to mathematics instruction. Nine states report a lack of funding for obviously needed staff development. Other states report lack of funding for materials and teacher salaries.[41]

41 Education Commission of the States, *State Initiatives to Improve Science and Mathematics Education* (Denver: ECS, 1987), pp. 1-13.

• Canadian National Initiatives

Traditionally, there have been no Canadian federal government programs targeted to the support of mathematics and sciences education at the elementary and secondary schools level. A number of federal programs have had small impacts on mathematics and science education, without being specifically targeted on these areas. One of these is the Canadian studies program of the Secretary of State (which has had, as one of its strategic areas for support, the canadian context of science and technology); another is the research support program of the Social Sciences and Humanities Research Council (whose strategic grants program has included "the human context for science and technology"). But, in general, federal officials have been content to point out that "education is a provincial responsibility."

Recently however, this apparent lack of interest has begun to change. Two initiatives were announced by the Prime Minister in 1988 at the National Conference on Technology and Innovation. The first of these is the Canada Scholarships program, which provides for scholarships for university students in science and engineering. While this is not exactly a program in support of science and education in schools its impact may yet be felt if the federal government follows through on its commitment, announced earlier but opposed by the Council of Ministers of Education, Canada, to base the awards on a national examination.

1 Science Culture Canada and the Campaign for Public Awareness of Science and Technology

The second federal program that is designed to have an effect, if somewhat indirect, on science education in schools, is the twin programs, Science Culture Canada and the Campaign for Public Awareness of Science and Technology. These programs were expanded following the Prime Minister's announcement in Toronto, Science Culture Canada having an annual budget of $2.5 million in 1988-89. While these programs are broader in scope than science and mathematics education alone, a number of projects have been supported both through Science Culture Canada and as part of the Campaign. For example, on the national scale, the Youth Science Foundation and its Québec counterpart, the Conseil de développement du loisir scientifique, received more than $600,000 in the current fiscal year from Science Culture Canada. For its part, the

Campaign supported the publication to every secondary school in Canada[42] of copies of two booklets for teachers on Technology and Innovation in Canadian Industry.[43] It also provided a grant of $25,000 to each provincial department of education for a project in support of science awareness at the elementary school level. Such grants were used in a variety of ways such as preparing a videotape on mussel farming (in Newfoundland).

2 National Research Council program of Technology Awareness

At the time of writing this program is still in its planning stages, but NRC is hoping to be able to link its Industrial Research field officers across Canada with schools in order to increase awareness of technology in schools. No details are available at present.

3 Private Sector Support for Science Education

Unlike in the United States, the Canadian private sector has not been very prominent in its support of science and technology education on the national level.

A notable exception is Northern Telecom which has developed a Science and technology Institute which makes awards for excellence in science teaching and participates in a number of other programs. Another initiative of note is the SEEDS (Science, Energy, Environment Development Studies) Foundation, which is based in Edmonton and is funded by corporations in the energy sector. This organization has produced materials for teaching about energy at all levels (now being translated into French) and has organized the highly successful Shell Merit Teacher Fellowship program at the University of Calgary each summer.

A number of other companies have initiated projects of a local nature within a given district. but only recently have plans for a more concerted initiative been developed.[44] And interest is clearly growing; the C.D. Howe Institute is working with its American counterpart, the National Planning Association, to determine ways in which their members are supporting educational activities.

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42 Except Québec, whose Deputy Minister of Education declined to have the materials circulated within the province.

43 Graham Orpwood, Douglas Wrigglesworth, and Tim Fielding, *Technology and Innovation in Canadian Industry*, information kits for science and social studies teachers (Ottawa: Ministry of State, Science and Technology and Orpwood Associates, 1989).

44 This initiative is sponsored by the National Advisory Board of the Canadian Advanced Technology Association and is still in its early stages of development.

And the Canadian Chamber of Commerce is developing a strategy to develop school-business alliances across the country.

• Canadian Provincial Initiatives

Many provinces have begun programs to promote the renewal of science education in their schools following the publication of the report of the Science Council of Canada in 1984. Many initiatives have been undertaken; the following selected examples will be highlighted. Only a few provinces are featured. This should not be taken to imply that, in other provinces, little is taking place. The scope of the present study did not permit, however, a full inventory of all initiatives in every province.

! British Columbia

In British Columbia, a sufficiently broad range of initiatives is taking place that any summary description is inadequate to cover them all. The following are perhaps the most significant:

a) The Association for the Promotion and Advancement of Science Education was established at the conclusion of the Science Council of Canada study in 1984. It has since established an Elementary Science Network to sustain and support the teaching of science in elementary schools. Its newsletter, published whenever grants can be obtained, goes to all elementary teachers in B.C. (and to Manitoba and Alberta also).

b) The Ministry of Education has introduced a new course, Science and Technology 11, a course whose focus is on science, technology and society, with a special emphasis on those areas of science and technology of most importance to British Columbia. The course has no textbook, in order that it may be kept current and relies heavily on videotaped material, in order to give students a window on the real science and technology taking place around them. This is a highly innovative course and, despite the fact that teachers are not well prepared to teach it, is likely to become a model for other provinces.

c) The province has recently had a Royal Commission (the Sullivan Commission) examining the education system and the Ministry of Education has responded to its recommendations. These include a common core curriculum for all students , including a K-12 strand on Science (including mathematics, science, environment and technology).

d) The Ministry of Advanced Education, Science and Technology has initiated a "Scientist in the Schools" program, which is designed to have provide for practising scientists to be linked with schools in various parts of the province, to visit these schools and to talk with teachers and students on a regular basis.

e) The Science Council of British Columbia has developed plans for a task force to support science education in the schools. Its terms of reference are still evolving.

2 Alberta

Alberta Education has been revising its science programs to reflect the need for students to know more about the nature of science, about the role of science in society and about technology. The goal is to produce decision makers and problem solvers rather than mere information memorizers.

The most significant of these changes is the development of a new integrated sequence of science courses at the senior high school level, Science 10-20-30, to supplement the present courses in Biology, Physics and Chemistry. These courses are designed to meet the needs of students who do not intend to study science at university but who wish to continue with some scientific study after grade 10.

At the same time, the province is continuing to develop its assessment procedures to ensure that "quality" in science education is "not mistaken for the amount of information that learners can recall but, rather, . . . associated with the ability to process and apply information in posing questions, analyzing issues, and making decisions."[45]

3 Saskatchewan

The province is in the midst of one of the most significant science education renewal programs it has ever undertaken. Following the program evaluation study of Dr Paul Hart, reported earlier, a consensus was established concerning the major components of the changes that were needed. Now, Saskatchewan Education is in the process of implementing these.

At the heart of the new program are 7 dimensions of scientific literacy that the program is intended to foster. According to this policy, the scientifically literate person is one who:

- *understands the **nature** of **science** and scientific knowledge;*
- *understands and accurately applies appropriate **science concepts**, principles, laws, and theories in interacting with society and the environment;*

[45] Information sheet from Alberta Education on science programs, dated 89 01 18, p. 5.

- *understands and appreciates the joint enterprise of* ***science*** *and* ***technology*** *and the interrelationships of these with each other and with other aspects of* ***society*** *and the* ***environment****;*

- *uses* ***processes of science*** *in solving problems, making decisions, and furthering understanding of society and the environment;*

- *has developed numerous* ***manipulative skills*** *associated with science and technology;*

- *interacts with the various aspects of society and the environment in a way that is consistent with the* ***values that underlie science****; and*

- *has developed a richer, more satisfying, and more* ***exciting view*** *of society and the environment* ***as a result of science education*** *and continues to extend this education throughout life.*[46]

These are further broken down into factors and organized according to the levels for teaching purposes. This development and implementation process is integrated into an overall renewal of the Saskatchewan curriculum and is expected to be complete by 1990.

4 Ontario

The present government of Ontario is placing an unprecedented level of emphasis on science and technology in the province. The highest profile programs are the Premier's Council and the Technology Fund but in education, science, technology and entrepreneurship are also being emphasised. A good example is the $3 million spent on the renewal of science education at the Primary and Junior levels (K-6). The Minister of Education appointed Dr Graham Orpwood as his Special Advisor to lead the development of this special program and the following 24 initiatives were undertaken.

Curriculum

1. *The Ministry of Education will issue a curriculum document outlining policy and direction for the science component of a balanced and integrated program in the Primary and Junior Divisions;*

2. *School boards will be expected to provide teachers with curriculum support documents for science in the Primary and Junior Divisions, based on the framework set out in the provincial curriculum document;*

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[46] See for example, *Science Education Curriculum Development Newsletter*, January 1988.

3. *The ministry will develop a Science Unit Purchase Plan in order to facilitate program development at the school board level;*

4. *Teachers will be expected to provide students with activities and experiences in such a way that the scientific attitudes, skills, and concepts identified in the provincial curriculum document will be developed.*

Support for Teachers

5. *The Ministry of Education will request the Ontario Association of Deans of Education to set up a task force to examine and advise on the specific preservice educational and training needs of teachers at the Primary and Junior levels in relation to science.*

6. *The ministry will offer four doctoral (or postdoctoral) fellowships to individuals choosing to specialize in science education at the Primary and/or Junior level.*

7. *Regulation 269 will be amended to provide for a three-session additional qualifications course, Science in Primary and Junior Education.*

8. *The Ontario Teachers' Federation (OTF) and its affiliates, the Science Teachers' association of Ontario (STAO), the Science Co-ordinators' and Consultants Association of Ontario (SCCAO), the Consultants and Co-ordinators' Association of Primary Educators (CAPE) and other scientific and educational organizations will be invited to develop an inventory of resource people for professional development in Primary and Junior science.*

9. *The ministry will invite the teachers' federations and other associations to designate science at the Primary and Junior levels as a priority area for professional development and to develop appropriate ways in which to express this priority to teachers.*

10. *The ministry will provide special grants to school boards in support of the development, testing, and reporting of innovative pilot projects in in-service teacher education in Primary and Junior science.*

11. *The ministry will support the development of an Ontario Elementary Science Network.*

12. *The ministry will publish an inventory of Ontario women in scientific and technical fields who are able to speak to children.*

13. *The ministry will seek the collaboration of professional organizations in hosting a major provincial conference in the spring of 1988 on science education in the Primary and Junior Divisions.*

14. School boards will be requested to review their policies with respect to the provision of curriculum support personnel and to increase such support in the area of science, where possible.

15. The ministry will arrange special workshops for superintendents and principals in connection with this renewal project.

Equipment and Learning Materials

16. School boards will be requested to review their allocation of funds for the purpose of materials required on an ongoing basis for the effective teaching of science and to increase these allocations where possible.

17. The Ministry of Education will co-operate with the Ontario Science Centre and the Science Co-ordinators' and Consultants' Association of Ontario in setting up a provincial Science Kit Development Program.

18. The ministry's Learning Materials Development Plan and French-Language Fund will designate science at the Primary and Junior levels as a priority area.

19. TVOntario will allocate funds for the development of video material of particular use in the teaching of science in the Primary and Junior Divisions.

20. The ministry's Computers in Education Centre will ensure that software development in support of Primary and Junior science education is consistent with the policies and directions set out in the provincial curriculum document.

Public Awareness

21. The Ministry of Education will design special communications strategies to inform parents, school trustees, and other members of the public about this renewal process.

Leadership, Implementation, and Evaluation

22. The Ministry of Education will second a specialist in Primary and Junior science to the Centre for Primary and Junior Education for two or more years.

23. The ministry will suggest to school boards that they develop "plans of action" for the renewal of Primary and Junior science within their jurisdictions.

24. During the 1989-90 school year, the ministry will review the progress of this renewal initiative.[47]

At the secondary level, revisions to the science curriculum are also being implemented. Of particular note here is the development of a new course at the OAC (grade 13) level, entitled "Science in Society."

5 Québec

Developments in Québec are taking place within the context of an overall reform of elementary and secondary education, which began in 1980 and 1981. As the new structures and programs are being progressively implemented through the system, questions and problems are arising and are leading to further modifications to all elements of the reform (i.e., content, pedagogy, graduation requirements and the approaches to evaluating outcomes).

It should be noted, however, that the principal source of all of the initiatives for change is the Ministry of Education itself. Compared with other jurisdictions, there appear to be fewer spontaneous activities arising from other sectors (such as school boards, teachers' organizations, industrial groups, etc.). On the other hand, extra-curricular science "leisure" activities are very active in Québec (for instance, science clubs). This means, however, that the initiatives for reform at the current time tend to be limited to the types of policy change open to ministries of education, such as changing curriculum guidelines, approval of new textbooks, and prescribing policies for courses within school programs.

Within this general context, the following changes may be noted at the elementary level: attempts to more completely integrate science into the general program of elementary education; the development of resource materials for teachers; and the setting up of an elementary school specially focused on science. Further, pedagogy in mathematics teaching has been the object of considerable attention, within the context of new program content.

At the secondary level, natural sciences and mathematics have been very much discussed in the present decade. Reforms of 1981 are still in the process of being implemented by the Ministry of Education. Important modifications were made in 1986 and the first graduates within the framework of the complete reform should be produced by 1992.

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47 *Science in Primary and Junior Education* (Toronto: Ontario Ministry of Education, 1986).

Streaming in science has been eliminated, and science courses have been made obligatory till the end of 4th year secondary. Obligatory science teaching has gone from 135 hours (pre-1981) to 300 and now (since 1986) to 400 hours of science, as well as 100 hours of initiation to technology. To this base may be added complementary courses in science.

The adjustments of 1986 resulted in a situation in which complementary courses, prerequisite for admission to numerous college programmes, have come to occupy a predominant position among available optional courses. This is due to reduction of the total number of options, as well as to the consequent reduction of effective optional course availability. This particularity of the college-prerequisite course sequence caused students to register for the complementary courses in numbers far exceeding expectations. This, in turn, lowered students' remaining options to take other courses, entailed high rates of dropout and failure in these advanced (complementary) science courses, and in consequence tended to diminish the level of the "advanced" courses.

At time of writing, the Ministry has proposed to redress this situation, *inter alia* by augmenting the number of hours of science study in 4th year secondary science by 50 hours and by revising the classification of pre-collegial prerequisites.

In the case of mathematics, since 1981 more hours have been added to the programme, and now total 600 hours obligatory registration of which 500 hours must be successfully completed. To this total may be added complementary courses as well. Questions similar to those posed in the case of the natural sciences have been expressed in the case of mathematics. Again, the Ministry has proposed recently to act on these criticisms, *inter alia* by re-analyzing the situation of pre-collegial prerequisite courses, as well as by augmenting by 50 hours the obligatory 4th year secondary regular mathematics course.

Recommendations of the Ministry have been criticized by the Conseil supérieur de l'éducation.[48] At time of writing, the outcome is unsure.

[48] In a first discussion of the general context of science and mathematics teaching at the secondary level, the Conseil supérieur de l'éducation mentioned the generally "good performance" ("bonne tenue") of Québec public school programmes; see *Les sciences de la nature et la mathématique au deuxième cycle du secondaire*, Avis au ministre de l'Éducation et ministre de l'Enseignement supérieur et de la Science, Québec, January 1989. In a recently published Advisory statement required in virtue of the advisory council's mandate, the proposed ministerial projects outlined here have come under more serious criticism. "Serious reserve" is expressed concerning a number of the proposals. Further, the Conseil suggests that the nature of the issues at stake might well lead the Minister to completely revise the pedagogical regime. See *Améliorer l'éducation scientifique sans compromettre l'orientation des élèves. Les sciences de la nature et la mathématique au deuxième cycle du*

It should, finally, be noted that studies produced by researchers in the field of science and mathematics education have underscored difficulties of the existing programmes. These criticisms deal, in particular, with alleged lack of social relevance of the content of science and mathematics courses, their scientistic and sexist bases, and their inability to produce in the graduates of the secondary programmes, rigourous scientific attitudes necessary for excellence in further study in these fields.[49]

6 New Brunswick

In this province, not only are developments being undertaken by the Department of Education, but the University of New Brunswick Science Departments are contributing also to the renewal of science education. The following 6 components of a science teacher upgrading program are being implemented using special Department of education grants to the faculty of science.[50]

1. Science for elementary teachers, a teleconferenced course has beeen offered in 10 locations throughout the province.

2. "recent advances in ..." (different aspects of science), another teleconference course aimed at high school science teachers.

3. A series of weekend workshops at UNB for teachers.

4. Full week workshops during the summer on broader topics such as "Fisheries and Aquaculture".

5. A two-week program for top students in the province on the subject of science and technology in society.

6. The support of local and regional science fairs.

Dr Michael Burt, who was responsible for initiating this program, attributes his success at obtaining funds to the fact that the program was clearly implementing the recommendations of the Science Council of Canada.

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secondaire, Avis au ministre de l'Éducation et ministre de l'Enseignement supérieur et de la Science, Québec, November 1989.

49 See comments and references in Conseil supérieur de l'éducation, *Les sciences de la nature et la mathématique au deuxième cycle du secondaire*, op. cit., p. 72, n. 23.

50 Professor Michael Burt, personal communication.

Other initiatives include unprecedented numbers of projects designed to increase the number of women choosing to study science and technology subjects. Other agencies involved in the renewal programs include non-profit groups, universities, textbook publishers, museums and science centres, and private corporations.

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Summary

Canada and the United States are in a state of frenetic activity aimed at renewing their systems of science and mathematics education, unequalled since the heady days of the 1960s when hundreds of millions of dollars were spent (in the U.S., principally) on the renewal of curriculum.

There are, however, important differences between the activity now and that which took place 25 years ago. A further analysis of the initiatives identified here is required in order to identify the distinguishing features of the latest initiatives and the directions these suggest for future activity in the field.

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